Addis Ababa Science and Technology University

A thesis submitted to School of Graduate Studies of Addis Ababa Science & Technology University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Road and Transport Engineering)

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Title

Assessments of Drainage Structure's Impact on Design Consistency of Highway Geometric Design: Case of Kombucha- Dessie Trunk Road, Ethiopia

Signed declaration

I hereby declare that the research work entitled "***Assessments of Drainage Structure's Impact on Design Consistency of Highway Geometric Design: Case of Kombucha- Dessie Trunk Road, Ethiopia***" submitted to the School of Graduate Studies of Addis Ababa Science & Technology University, is a record of an original work done by me under the guidance of Dr. Tilahun Derib (Ass. Professor), Lecturer at Addis Ababa University (Ethiopian Institute of Architecture, building construction and City development), and this research work is submitted in the partial fulfillment of the requirements for the award of the degree of Master of Science in Civil Engineering (Road and Transport Engineering).

The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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Abstract

Geometric design of highway is a process of determining the layout and dimensioning of the cross-sectional elements of a given road section like, width of traffic lane and shoulder, longitudinal, crown and side slope values.

Geometric design consistency is application of similar design characteristics in the process of highway geometric design that will not affect safety and operation of road users and that will not force abrupt change in driver's behavior. A road with consistent geometric design is the one with almost similar geometric features and permits drivers to act at uniform behavior.

One of such road elements that may affect geometric consistency of highway are Bridges and culverts. Due to high construction cost of Bridges and culverts, it is very common to see such structures constructed narrower than relative approaching road section and at the lowest point of sag vertical curves. On bridges and culverts that have designed and constructed on lowest point of vertical curve and at sharp horizontal curve locations, it becomes very difficult for the drivers to operate at 85th percentile speed without facing traffic accident. Therefore, when we see with this respect bridges and culverts currently being serving are vulnerable for traffic crash accidents. For countries like Ethiopia which has placed on the leading position for its traffic accident rate, it is very crucial to work towards eliminating or minimizing such crash vulnerable zones in the road section.

This research reveals the effect of drainage structures on the geometric design consistency of highways. The 85th percentile operating speed and traffic crash rate has been used as a variable to measure the effect of bridges and culverts on road geometric consistency. Observed traffic speed data on Kombolcha to Dessie road section and recorded traffic accident data was used to show the influence of these drainage structures on speed and traffic accident rate. Linear regression equation with two explanatory (independent) variables has been used to show the variation of 85th percentile operating speed at bridge and culvert crossings at horizontal curve with length of radius at horizontal curve and provided horizontal clear distance between road edge and obstruction on horizontal curve. This is because observed speed data on bridge and culvert located on horizontal curves show that radius of horizontal curve and clear horizontal distance between road edge and roadside obstruction has an impact on operating speed. Therefore, 85th percentile operating speed has treated as dependent variable (Y), length of radius as independent variable-1 (X_1) and clear horizontal distance b/n road edge and obstruction as independent variable-2 (X_2). On the other hand, traffic crash frequency is used for measuring accident vulnerability of bridges and culverts. Fatal, incapacitating (severe injury), minor injuries and property damages per million vehicle kilometers has been used to measure contribution of bridges and culverts on traffic accident rate for Kombolcha – Dessie road section.

One tailed t-test at confidence level of 95% for variation of 85th percentile speed b/n bridge and culvert crossings and tangent section shows that there is significant variation (reduction) of speed at bridge and culvert locations. Accident per million vehicle kilometers indicate that bridge and culvert locations are about 4 times the accident per million vehicle kilometers on non-Bridge road sections. This is a consequence of sudden change of speed due to sight distance problem and lack of lane widths at bridge/culvert locations.

Review of provided horizontal clear distance b/n road edge and obstruction on ten bridge locations as per the required clear distance for sight distance provision, all bridge locations considered lack

sufficient clear distance and coefficient of determination for the multiple regression equation ($R^2 = 0.86$) had indicated that 86% of the value of operating speed at bridges and culverts located on horizontal curve is explained by the radius length and clear distance provided b/n obstruction and road edge.

Table of Contents

Contents

Abbreviations

AACRA	Addis Ababa City Roads Authority
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
BFPR	Board of Fire Prevention Regulations
CMVK	Crash per million Vehicle Kilometer
CMVM	Crash per million Vehicle Miles
ERA	Ethiopian Roads Authority
FLNRO	Forest, Land and Natural Resource Operation
HCM	Highway Capacity Manual
HPMS	Highway Performance Monitoring System
LRFD	Load Resistance Factor Design
NAASRA	National Association of Australian State Road Authority
ORA	Oromia Roads Authority

List of Figures and Tables

List of Tables

List of Figures

List of Photos

Chapter 1: Introduction

1.1 General introduction

Road safety is one of the most important problems in the world. Every year 1.2 million people are killed, and 20–50 million people are injured in road accidents. If current trends continue, traffic accidents are predicted to be the third leading contributor to the global burden of disease and injury by 2020(Camacho-Torregrosa *et al.*, 2013). Highway design which ensures that successive elements are coordinated in such a way as to produce harmonious and homogeneous driver performances along the road is considered consistent and safe. On the other hand, an alignment which requires drivers to handle high speed gradients and does not meet drivers' expectancy is considered inconsistent and produces higher crash frequency(Montella and Imbriani, 2015). Alignment is one of the components of geometry and an abrupt change in the alignment is a leading cause for crashes in rural highways. Presence of a curve after a long tangent or a sharp curve after a flat curve is an example for inconsistency in the alignment. Such an alignment brings about unnecessary and unhealthy speed changes that may lead to crashes. Thus, a highway design can be evaluated based on consistency in geometry(Jacob, Dhanya and R, 2013).

A measure of the road design is the consistency. Design consistency is defined as the relationship between the geometric characteristics of a highway and those conditions the driver expects to encounter. When the design is consistent with what the driver expects to find, the highway is also consistent. This reduces the possibility of driving errors and unsafe maneuvering(Garach Morcillo *et al.*, 2014). Design consistency refers to a highway geometry's conformance with driver expectancy. Generally, drivers make fewer errors at geometric features that conform to their expectations than at features that violate their prior expectancies. Thus, a design inconsistency in a roadway segment implies a geometric feature or features that violate driver expectancy, such as an abrupt change in roadway geometry. Surprising drivers by violating their expectancies increases the chance of delayed response times, speed errors, and unsafe driving maneuvers that may lead to higher crash risk. To avoid these problems, designers should ensure that the roadway design complies with driver expectations through the evaluation of design consistency, and the redesign of inconsistent locations (Dwikat, 2014).

The above stated definitions for road inconsistency is based on driver's perception and expectation about the road ahead of them. But, road inconsistency can also be seen from conformance with the national highway design manual guidelines. Every nation has its own Highway design manual for example in case of Ethiopia there are different manuals that are applicable on federal and state levels like, ERA design manual, AACRA design manual and ORA design manual. With this respect two road sections which have the same design class, Traffic volume and passing through the same topographic area should have the same geometric features, unless the designer is lacking stickiness to the national highway design manual which is the root cause of road inconsistency.

Indeed, the concept of measuring highway inconsistency has very low concern in countries like Ethiopia whose strong concern is to construct the transport facility yet. But, unfortunately Ethiopia is also the leading country in the world with respect to traffic crash accident rate. One of the main cause for such high number of road accident is road geometric design inconsistency. Therefore, more work should be done towards minimizing highway design inconsistency.

1.2 Background of the study

Dessie to Kombolcha Road section is 20.9 km with so many interconnected horizontal curves, a number of drainage structures and very short side clearance distances on horizontal curve locations. Due to this fact operating speed and crash frequency on bridges and culverts are selected as research variables for this study.

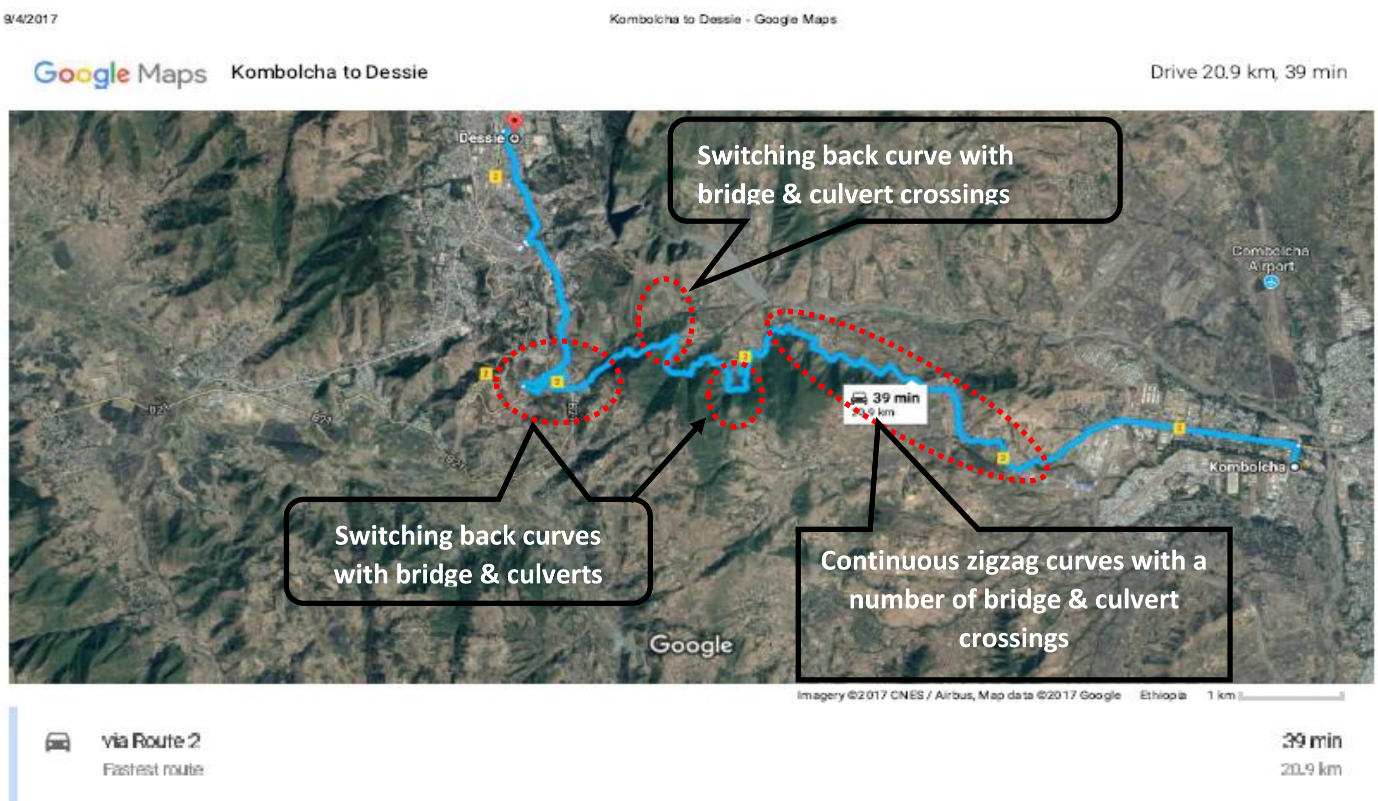

Figure 1.1Dessie – Kombolcha Road (source: Google map)

Figure 1.1 showed that the road kombolcha to Dessie has zigzag and sharp horizontal curves with smaller radius. The existence of a number of bridge and culvert crossing within sharp curves make Kombolcha – Dessie road more sensitive area for traffic accident and driving speed limit. Due to this fact drivers are forced to change their driving speed continuously which intern affects the design consistency of road segment.

Design inconsistency is a major problem of many country's road network that needs greater attention but, difficult to measure. This is because it can be affected by many different factors that makes formulation of a single model to determine the inconsistency value is more complex. As it has well defined above geometrically inconsistent road is the one that forces drivers to continuously change their driving characteristics and that doesn't conform to their prior expectations about the road alignment ahead of them. Continuous change of driving characteristics is a response to deviation of the actual road condition from the driver's prior expectation and it is an indication of existence of geometric design inconsistency. But, the most important point is determination and measurement of factors that made a given road section non-uniform and unpredictable by the drivers and road users in general.

Most of the research and development of design consistency measures focuses on four main areas: operating speed, vehicle stability, alignment indices, and driver workload. Operating speed evaluation is the most commonly used criteria to evaluate highway design consistency. However, the most commonly used method to evaluate road consistency was developed by Lamm et al. (1999) based on mean accident rates. They have also presented two design consistency criteria related to operating speed, which include the difference between the design and operating speeds and the difference between the operating speeds on successive elements (Camacho-Torregrosa *et al.*, 2013). Accident rate and the difference between operating and design speed are variables that are used to measure road geometry consistency.

Generally, road geometric features like, lane width, steep grades, sharp horizontal and vertical curves and existence of narrow drainage structures, specifically bridges are the main causes for road geometry inconsistency. In this research effect of drainage structures on the road alignment inconsistency has discussed in relation to road traffic accident rate and operating speed (V_{85}). Actually, drainage structures are not the only causes of highway geometric inconsistency. Short horizontal and vertical curves and insufficient side clearance on horizontal curve locations are the other factors that affect consistency negatively.

In this research the effect of Bridges and Culverts in relation to horizontal curves, vertical curves and side clearance distance on the highway inconsistency has discussed in terms of change of operating speed (V_{85}) and traffic accident rate. But, since the main objective of this research is to reveal the effect of drainage structures on road inconsistency, a great concern had given for the relation between these two parameters. In addition to operating speed, level of service and road traffic accident rate had discussed in relation to drainage structures as a measure of highway inconsistency.

1.3 Statement of the Problem

Ethiopia is one of leading countries in traffic accident rate in the world as well as in Africa. According to the World Health Organization's (WHO) report, published in April 2014, traffic accidents in Ethiopia account for the deaths of 37.28 persons per 100,000 vehicles. This is 2.77% of the total deaths in the country, placing Ethiopia 12th in the world. Among many factors that contribute lack of design consistency on a road section is a major factor. Road alignments that lack geometric design consistency forces drivers to change their driving character continuously which may lead them to traffic accidents and minimize level of service of the road.

The total length of bridge and culvert crossings are insignificant compared to that of the total length of a road section. But, they have visible effect in minimizing operational speed of drivers and increasing total traffic accident rate on a given road section. The main reason that makes bridge and culvert crossings such influential locations on speed and traffic accident rate is lack of design consistency followed while designing these structures. It is very common to us to observe bridge and culvert locations with narrower traffic way than the approaching road, bridge and culverts without animal and pedestrian crossings, without approaching guard rails and broken guard rails, culverts and bridges located on the lowest point of vertical curve and at the midpoint of sharp horizontal curves that impedes sight distance requirement of drivers. This is because to minimize bridge and total project construction cost. But, traffic accident statistics data shows that such drainage structure zones are very vulnerable for traffic crash accidents. Six years traffic accident record for federal roads show that 806 out of 80,293 accidents happened on bridge and culvert crossings while 13 out of 255 accidents recorded on Kombolcha to Dessie road happened on bridge and culvert crossings. Accident statistics data also showed that majority of accidents happened on bridges and culverts goes to fatal accidents.

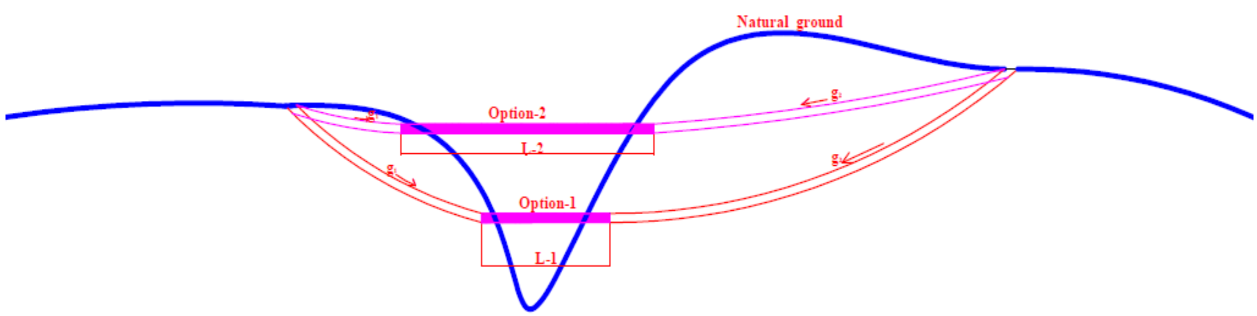

Figure 1.2 Shows effect of Bridge elevation on the sigh distance.

Even it is very common to see straight or tangent bridge slabs within horizontal curve zone i.e. bridge slabs are not constructed radially along the horizontal curve alignment and even it will not be supper elevated. Sudden transition from supper elevated and curved sections to normal crowned and tangent section is very dangerous because a driver driving at maximum speed at supper elevated section may face a collision or falling to river valley accident from river crossing structures due to the effect of centrifugal force. The figure below with blue color shows a design trend for bridge and culvert structures within circular curves.

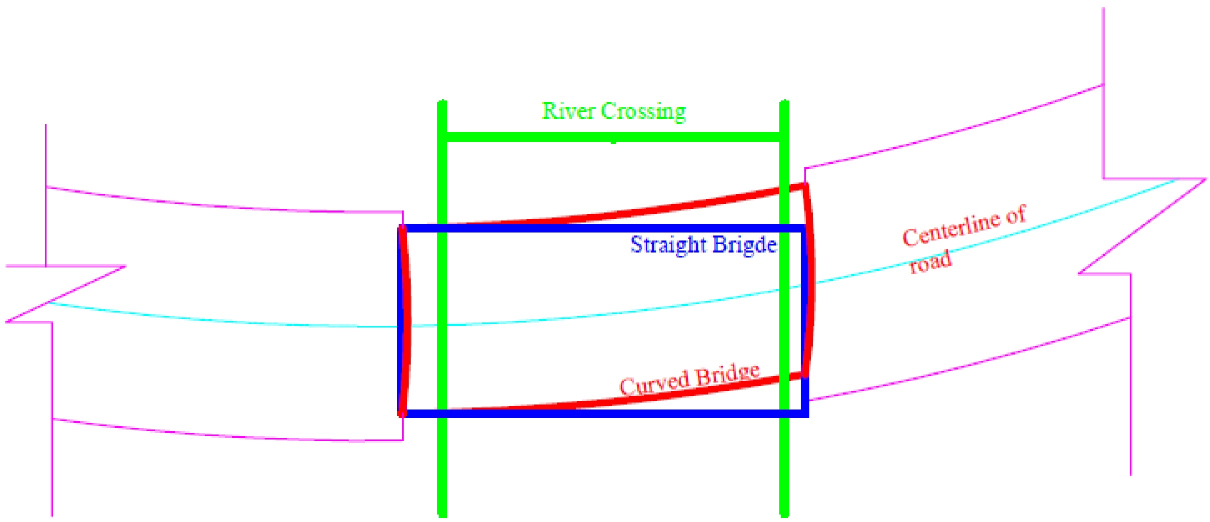

Figure 1.3 showing effect of inserting Straight Bridges within circular curves on the Road geometry.

As it can be seen on the above two figures, in most cases the depressed location of drainage structures at vertical curves and Sharp horizontal curves with small radius and insufficient horizontal clearance of obstructions like tree and mountain toes are hazardous locations for traffic accident.

Road users' safety is the most binding control point in the design of highway alignment. Therefore, the life of road users and property damage should be given greater consideration than construction cost of road projects. To meet safety requirements around drainage structure crossings, they should be constructed with sufficient traffic lane width, at optimum grade that provide sufficient sight distance and should be aligned with a road alignment and supper elevated if it is located at horizontal curve.

1.4 Research objective

The main objective of this research work is to show effect Drainage Structures on design consistency of highway geometric design by using highway operational characteristics like operating speed and traffic accident frequency.

As a specific objective, the research tries to show the effect of Bridges and Culverts on the 85^{th} percentile operating speed value. Especially, effect of radius of horizontal curve on which bridge or culvert is located on 85^{th} percentile operating speed and the relation between frequency of traffic accident in terms of number of crashes per million vehicle kilometers (CMVK) with number of bridges and culverts on Kombolcha to Dessie road section. It also shows severity rate per accident types by comparing accidents on Bridge and culvert locations with those accidents happened off bridge and culvert.

The basic research Questions that has been answered the research includes;

i. Do drainage structures have a significant effect on 85^{th} percentile operating speed of a road section?
ii. How much are drainage structures vulnerable for traffic accidents compared to other sections of the road?

1.5 Scope and Limitations

The scope of this research is limited to roads constructed in Ethiopia that have similar geometric characteristics and similar number of bridge and culvert ratio per kilometer with Dessie to Kombolcha road.

Due to time and resource limitations field observed speed data for Kombolcha to Dessie road section was used show the combined effect of bridge and culvert crossing and radius of horizontal curve on 85^{th} percentile operating speed. As a result, the result of the research work tells only about sample road project considered and it may not be used for characterizing the whole road network in Ethiopia. There is no adequate research made so far on design consistency in Ethiopia. For this reason, literatures from other countries that are prepared on design consistency have been used as references.

1.6 Structure of the Thesis

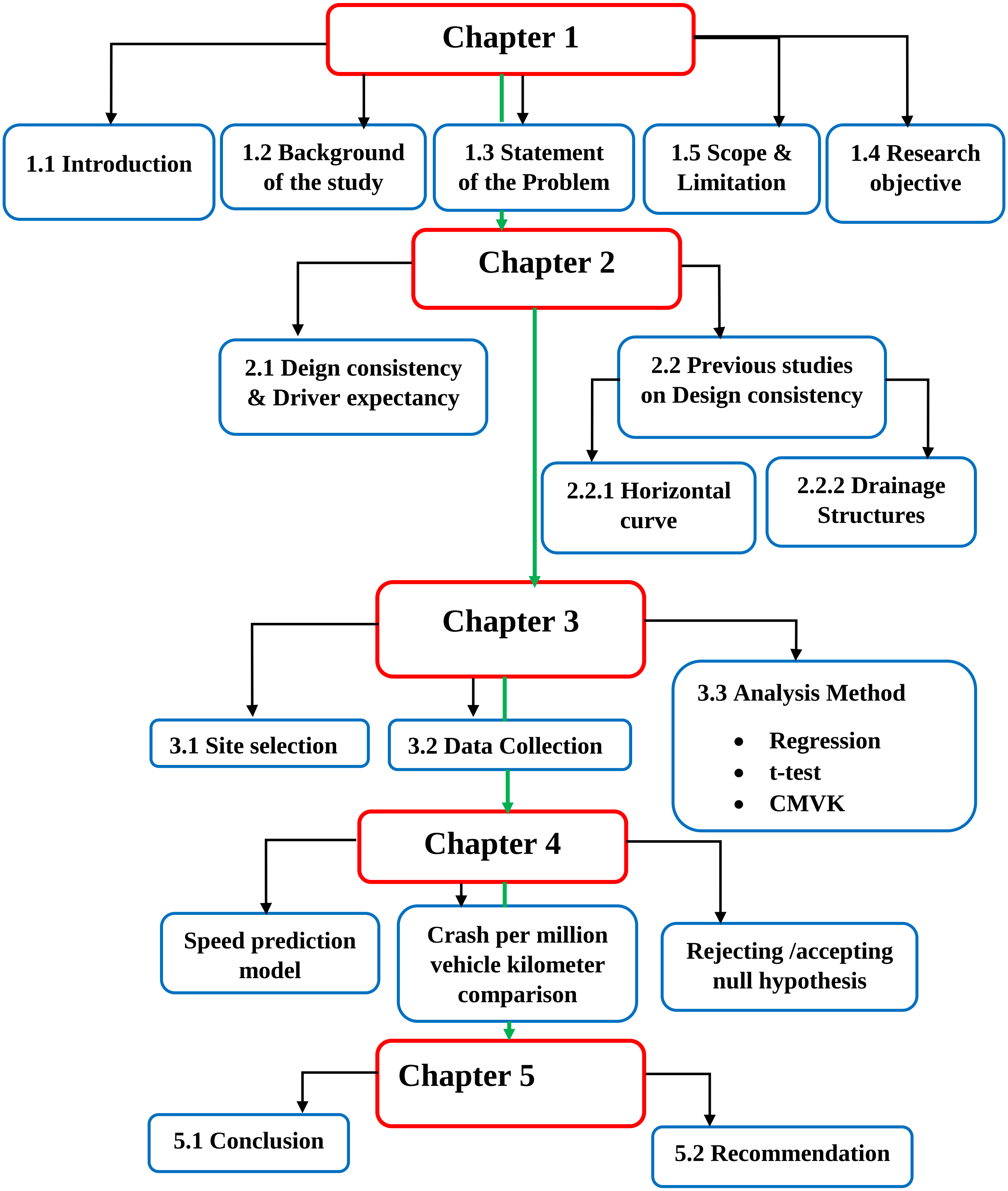

Figure1.4 Structure of the Thesis

Chapter Two: Literature review

2.1 Geometric consistency and driver expectancy

Geometric design for transportation facilities includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections, and various design details. Although the details of design standards vary with the mode and the class of facility, most of the issues involved in geometric design are similar for all modes. In all cases, the goals of geometric design are to maximize the comfort, safety, and economy of facilities, while minimizing their environmental impacts.

The goal of transportation is generally to provide safe and efficient movement of people and goods. To achieve this goal, designers use many tools and techniques. One technique used to improve safety on roadways is to examine the consistency of the design. Design consistency refers to a highway geometry's conformance with driver expectancy. Generally, drivers make fewer errors at geometric features that conform to their expectations than at features that violate their prior expectancies.

Design consistency implies that the design or geometry of a road does not violate either the expectation of the motorist or the ability of the motorist to guide and control a vehicle in a safe manner. Keeping a roadway consistent in design is important because it is believed that motorists make fewer errors at geometric features that conform to their expectations than at features that violate their expectancies. An inconsistency in design can be defined as a geometric feature or combination of adjacent features that have such unexpectedly high driver workload that motorists may be surprised and possibly drive in an unsafe manner.

A consistent alignment is important because the relationship that exists between consistency and safety. The inconsistencies that exist on a roadway can produce a sudden change in the characteristic of the roadway, which can surprise motorists and lead to speed errors. These speed errors result in critical driving maneuvers for motorists and an unfavorable level of accident risks. These design inconsistencies arise when the general character of alignment changes between segments of the roadway. A consistent alignment would ensure that most drivers would be able to operate safely at their desired speed along the entire alignment.

So far there are different researches undertaken on geometric design consistency. Definitions provided and criterions used to measure consistency of road geometry was more or less similar. The design consistency evaluation is one of several promising tools that can be employed by roadway designers to improve roadway safety performance: design inconsistency in a roadway segment can surprise drivers by violating their expectancies and increasing the chance of delayed response times, speed errors, and unsafe driving maneuvers that may lead to higher collision risk. Design consistency refers to the condition where in the roadway alignment does not violate driver expectations (Russo, Mauro and Dell'Acqua, 2012). According to US department of transportation, design consistency refers to the conformance of the highway geometry to driver expectancy(US Department of Transportation, 2000). Highway design which ensures that successive elements are

Coordinated in such a way as to produce harmonious and homogeneous driver performances along the road is considered consistent and safe. On the other hand, an alignment which requires drivers to handle high speed gradients and surprising events and does not meet drivers' expectancy is considered inconsistent and produces higher crash frequency(Montella and Imbriani, 2015). Morcillo, Poyo and Fernandez have defined design consistency as the relationship between the geometric characteristics of a highway and those conditions the driver expects to encounter. When the design is consistent with what the driver expects to find, the highway is also consistent. This reduces the possibility of driving errors and unsafe maneuvering(Garach Morcillo *et al.*, 2014). In another study Jacob and Dhanya have defined geometric design consistency as a good design of highway geometry that necessitates proper coordination of straight and curved sections, so that drivers will not be surprised by a change in the alignment(Jacob, Dhanya and R, 2013). A design inconsistency in a roadway segment implies a geometric feature or features that violate driver expectancy, such as an abrupt change in roadway geometry. Surprising drivers by violating their expectancies increases the chance of delayed response times, speed errors, and unsafe driving maneuvers that may lead to higher crash risk(Dwikat, 2014); whereas design inconsistency is described as a geometric feature or combination of features with unusual or extreme characteristics that drivers may drive in an unsafe manner(Dwikat, 2014).

Highway design which ensures that successive elements are coordinated in such a way as to produce harmonious and homogeneous driver performances along the road is considered consistent and safe. On the other hand, an alignment which requires drivers to handle high speed gradients and does not meet drivers' expectancy is considered inconsistent and produces higher crash frequency. To increase the usefulness and the reliability of existing safety performance functions and contribute to solve inconsistencies of existing highways as well as inconsistencies arising in the design phase, there should be safety performance functions for highways that incorporate design consistency measures(Montella and Imbriani, 2015).

Almost all of the above definitions provided by different researchers are similar. The definitions try to correlate design consistency with uniformity of speed and crash accident rates which are functions of capacity of road geometry to meet driver's prior expectation.

Expectancy, in general, can be thought of as a set of possible probabilities regarding a given situation. Those probabilities are subjective and are based upon learned and experienced events. An operational definition of expectancy with regard to transportation relates to the observable and measurable features of the driving environment which,

1. Increase a driver's readiness to perform a driving task in a particular manner, and

2. Cause the driver to continue in the task until it is completed or interrupted.

A similar definition was provided by Alexander and Lunen Feld as, expectancy relates to a driver's readiness to respond to situations, events, and information in predictable and successful ways.

Attempts to learn about and to provide information to the designer regarding design consistency and driver expectancy have been the subject of several major research projects and reports. In general, they can be grouped into the following areas: vehicle operations-based consistency, roadway geometrics-based consistency, driver workload, and consistency checklists. The most common vehicle operations-based consistency measure is operating speed, although other methods such as conflicts and accidents have been suggested. A method for using geometrics-based consistency focuses on evaluating the consistency of the design using only information that would be typically available from a set of roadway plans. Driver workload assumes that there is a relationship between the effort required to perform a task and the roadway geometrics presented during that performance. Checklists largely consist of reminders to designers to examine design features for possible expectancy violations (US Department of Transportation, 2000).

A recently embraced premise for roadway design is the development of such a design where the roadway itself provides the clues to the drivers regarding their operating speeds. Therefore, a requirement placed on roadway design is meeting driver expectations by creating a consistent roadway design. Driver expectancy is formed by experience and has a significant influence on the driving task, since it can increase the driver's readiness to complete a task. A consistent speed environment that conforms to driver expectations is desirable to avoid abrupt changes in operating speeds and thus create a safe operating environment(Materials *et al.*, 2007a).

2.2 Previous Studies on Design Consistency

The design consistency models are based in four main measures: operating speed, vehicle stability, alignment indices, and driver workload. Operating speed is the most visible indicator of inconsistencies because when the design of a roadway violates driver expectancy, the driver usually reduces the speed of the vehicle. Operating speed is defined as the speed selected by the drivers when not restricted by other users, i.e., under free flow conditions, and it is normally represented by the 85th percentile speed, denoted as V_{85}(Garach Morcillo *et al.*, 2014).

There are different research researchs that had been done on geometric design consistency and how to measure the inconsistency value. As it is already mentioned on the introduction section a great emphasis has given to the effect of drainage structures as cause for highway geometric design inconsistency and operating speed, traffic accident rate, vehicle stability and level of service as a parameter for measuring inconsistency.

Evaluating the consistency of geometric design is one of the promising strategies for improving the rural highway safety as sections that lack design consistency experience high collision occurrences. The available methods for evaluating consistency are speed based, vehicle stability based, alignment indices based and driver workload based. Among the available methods, operating speed based approach can be reckoned as the most efficient and widely used. This is because speed is a visible indicator of consistency. Also, operating speed and speed variations can be easily observed and measured (Jacob, Dhanya and R, 2013).

Geometric design consistency evaluations are a widely used method of determining sections of highways which require alignment improvement. This method identifies geometric inconsistencies on highways by means of design evaluation criteria. Following such assessments, the allocation of funding to reduce the geometric inconsistencies can be prioritized. To conduct a geometric design consistency evaluation a great deal of information is required. Generally, geometric design consistency measures are divided into four distinct categories. Operating speed, vehicle stability, driver workload and alignment indices(Watters, 2007). A Study on design consistency by Garach

Morcillo and his colleagues indicate that the design consistency measuring models are based on four main measures: operating speed, vehicle stability, alignment indices, and driver workload. Operating speed is the most visible indicator of inconsistencies because when the design of a roadway violates driver expectancy, the driver usually reduces the speed of the vehicle(Garach Morcillo *et al.*, 2014). Researches in design consistency focused on quantifying measures of design consistency and developing models and evaluation criteria to identifying them. The measures can be classified into four main classes: operating speed, vehicle stability, alignment indices, and driver workload(Dwikat, 2014). Most of the research and development of design consistency measures focuses on four main areas: operating speed, vehicle stability, alignment indices, and driver workload(Camacho-Torregrosa *et al.*, 2013).

As it can be noted on the above statements, in most of research researchs speed, alignment indices and driver's work load are the main parameters that have been used to measure geometric design consistency. The other important parameter that should be taken into consideration while measuring design consistency is crash accident rate that is recorded on a given road section. This is because road alignments with deficiency in design consistency are highly exposed to traffic accidents. Therefore, in this research greater emphasis is given to speed, alignment indices and crash rate recorded on road segment to measure road geometric design consistency. Horizontal curve and bridge and culvert locations are selected for this study to collect data on crash rate, alignment indices and speed variability.

So far, research works undertaken on geometric design consistency have used different approaches to measure design consistency in terms of speed, alignment indices and crash rate. Here under approaches used by different researches to measure design consistency has stated briefly both on horizontal curves and drainage structure crossings.

2.2.1 Horizontal curves

2.2.1.1 Operating Speed Approach

In most researches, operating speeds has given a strong concern to measure road consistency. But, the way that researchers have used to determine operating speed variation to be used as an indicator of highway geometry inconsistency varies from one another, while they follow the same criteria to describe the level of inconsistency which is based on the value of speed variation. Generally, when we are referring about speed, speeds on road segment can be classified into three i.e. operational speed, design speed and posted speed limit.

Operating speed is defined as the speed selected by highway users when not restricted by other users, and is normally represented by the 85^{th} percentile operating speed. In terms of geometric design consistency, operating speed (V_{85}) is widely considered to be the most notable and straightforward geometric design consistency measure. The change in speed of vehicles is a visible indicator of inconsistency in geometric design. The operating speed can be used in consistency evaluation by examining the variation between the design speed (V_D) and V_{85} on a particular section of highway or examining the differences between V_{85} on consecutive highway elements (ΔV_{85})(Watters, 2007). On his research Watters has used two criteria, change in operating speed ($\Delta V85$) and difference between operating speed and design speed ($V_{85} – V_D$) to classify the road alignment as good, faire and poor alignment.

Table 2.1 Design consistency evaluation criterion based on design and operating speed variation

Design Evaluation	Criterion-1	Criterion-2
GOOD	$\lvert V_{85} - V_d \rvert \leq 10$km/hr.	$\Delta V_{85} \leq 10$km/hr.
FAIR	10km/hr. $\leq \lvert V_{85} - V_d \rvert \leq 20$km/hr.	10km/hr. $\leq \Delta V_{85} \leq 20$km/hr.
POOR	$\lvert V_{85} - V_d \rvert \geq 20$km/hr.	$\Delta V_{85} \geq 20$km/hr.

Source: (Watters, 2007)

Note: Good = no highway alignment corrections are required, *Fair* = no alignment correction is required, but corrections may be desirable to signs, camber etc.; and Poor = alignment redesign is recommended.

These are the most well-known set of safety criteria. However, they may suffer from several shortcomings. Criterion I, for example, would suggest there is no difference between a value of 10.1 km/hr. for $|V_{85} – V_D|$ and a value of 20.0 km/hr. for $|V_{85} – V_D|$. They both lie in the same category "Fair". But values of 19.9 km/hr. and 20.1 km/hr. for $|V_{85} – V_D|$ lie in two different categories, "Fair" and "Poor" respectively. This creates a step form of the two criteria and is a problem which needs concern. The same step form of criteria exists for Criteria II(Watters, 2007).

Operating speed evaluation is the most commonly used criteria to evaluate highway design consistency. The operating speed, often defined as the 85th percentile speed (V_{85}) of a sample of vehicles under free-flow conditions, can be estimated by means of operating speed models. This specific measure of speed can be used for consistency evaluation by examining the discrepancies between design speeds (V_d) and operating speed or examining the operating speed decrement between successive elements of the road (ΔV_{85}). The difference between operating speed and design speed |V85-Vd| is a good indicator of the inconsistency at one single element, while the speed reduction between two successive elements (ΔV_{85}) indicates the inconsistency experienced by drivers when traveling from one element to the next one(Camacho Torregrosa, FJ.; Pérez Zuriaga, AM.; Campoy Ungria, JM.; García García, 2013). Similar to that of Professor Watters, Lamm has used two criterions which are based on difference between design and operating speed and variation of operating speed on different spots of road section to measure design consistency.

Table 2.2 Thresholds for variation of speeds to determine design consistency quality.

Consistency rating	Criterion-1 (km/hr.)	Criterion
Good	$\lvert V_{85}-V_d \rvert \leq 10$	$\lvert V_{85i} – V_{85i+1} \rvert \leq 10$
Fair	$10 \leq \lvert V_{85}-V_d \rvert \leq 20$	$10 \leq \lvert V_{85i} – V_{85i+1} \rvert \leq 20$
Poor	$\lvert V_{85}-V_d \rvert >20$	$\lvert V_{85i} – V_{85i+1} \rvert > 20$

Source:(Camacho Torregrosa, FJ.; Pérez Zuriaga, AM.; Campoy Ungria, JM.; García García, 2013)

Other studies, such as the one carried out by Polus and Mattar-Habib (2004), used continuous speed profiles to determine the global speed variation along a road segment, and determining a single consistency value for the whole road segment. Moreover, their design consistency index is a continuous function instead of being based on ranges. They developed two new consistency measures. The first was the relative area bounded between the operating speed profile and the line of average weighted speed by length (Ra). The second was the standard deviation of operating speed in each design element along the whole section investigated (σ). It was necessary to use this additional measure to complement the first measure because the Ra measure by itself provided similar results for somewhat different geometric characteristics in a few cases.

Based on the two independent measures, a consistency model was developed; and thresholds for good, acceptable, and poor design consistency of any section were proposed. The Ra and σ on several test sections provided a similar assessment of consistency as Lamm's measures(Camacho Torregrosa, FJ.; Pérez Zuriaga, AM.; Campoy Ungria, JM.; García García, 2013).

Table 2.3 Thresholds for determination of design consistency quality according to Polus and Matter-Habib.

Design Consistency Quality $C = e^{-0.278*[Ra*(\frac{\sigma}{3.6})]}$		
Good	**Acceptable**	**Poor**
C > 2 (m/s)	**1< C ≤ 2 (m/s)**	**C ≤ 1 (m/s)**

Source:(Camacho Torregrosa, FJ.; Pérez Zuriaga, AM.; Campoy Ungria, JM.; García García, 2013)

Another influencing factor on travel speed is the roadway characteristics. Research reports shown that the curvature, grade, length of grade, number of lanes, surface condition, sight distance lateral clearance, number of intersections and built-up areas near the roadway are significant factors that could contribute to the speeds at which drivers operate their vehicles. Warren and Tignor (1990) found that the number of access points and nearby development such as proximity to tall objects to the road has the greatest influence on vehicle speeds. Another research by Fildes (1987, 1989) found that road width and number of lanes are the two most important characteristics that influence the operating speed. Besides these factors there are always the environmental conditions. Greater speed reductions were observed when weather conditions have gotten worse (Materials *et al.*, 2007a).

According to report of UK University of KENTUCKY, design speed has been the controlling factor in selecting the components of vertical and horizontal roadway alignment since the 1930s. At about the same period, the practice of selecting posted speed limits on statistical analysis of vehicular speeds was initiated. Speed limits have been typically set based on the 85^{th} percentile speed. The intrinsic assumption here is that the driver is able to determine and follow the appropriate speed to travel on the roadway. This assumes that the roadway will provide the driver with adequate information to decide the appropriate speed. Given these basic assumptions, design speeds should be selected in a way that would create a safe operating speed and will not introduce abrupt changes in operating speeds between roadway sections. There are cases however that this principle does not hold. In such cases, the designer needs to intervene and provide additional information to the drivers to assist them in adjusting their speed. This information is typically provided by signs, warning and regulatory, as well as pavement markings(Materials *et al.*, 2007a).

One of the fundamental elements of roadway design is the design speed, since it has the potential to affect almost every roadway design aspect. Most of the studies that have dealt with safety and speeds typically considered speed limit and thus, little is known about the influence of design speeds on safety. It could be assumed that there are some relationships between design speeds and speed limits, but it is not feasible to develop a systematic relationship due to the methods used to establish speed limits in many states. Moreover, of interest to highway designers is the determination of whether there are any safety consequences from improper transition between design speeds when entering and exiting a rural community. Current design approaches for highways emphasize speed as a surrogate for quality and efficiency(Materials *et al.*, 2007a).

In order to develop roadway sections that are consistent in design, there is a need for design speed, operating speed and posted speed limit to be reasonably similar. By doing so, a safe and consistent speed environment that conforms to driver expectations can be created. The design process, as it is promoted in "A Policy on Geometric Design of Highways and Streets" (Green Book) is inconsistent because it uses the design speed of the most restrictive geometric element (such as a horizontal or vertical curve) for the design of roadways. Such an approach pays little attentions to transitions between curves and tangents and therefore can cause an abrupt change in the driving pattern, which in turn can lead to speeding related errors(Materials *et al.,* 2007a).

There are several factors that could affect speed related to the driver (age, gender, attitude, perceived risks), environment, vehicle and roadway (geometry, transition, weather). This research particularly focuses on relation between speed and roadway geometry. A study that was made by Mustyn and Sheppard found that more than 75% of drivers considered on the study claimed to have driven at speeds greater than the posted speed limit as the roadway was permitting them to do so. According to the participants of the study, crossing the speed limit by 10 mph was not an unlawful thing to do but they considered driving in excess of 20 mph as a serious offense. This implies that it is not only the road geometry deficiency that causes road inconsistency but, deviation between posted speed limit and operating speed also plays a greater role in road inconsistency.

In the case of Ethiopia lower posted speed limits cannot be treated as inconsistency causing factor. This is because as long as the roadway can permit higher operating speed drivers don't respect posted speed limit especially on the rural road sections.

Let us see effect of road geometry on the three speed values one by one;

2.2.1.2 Design Speed

Design speed has been the controlling factor in selecting the components of vertical and horizontal roadway alignment since the 1930s. Speed limits have been typically set based on the 85th percentile speed. As previously used, design speeds should be selected in a way that would create a safe operating speed and will not introduce abrupt changes in operating speeds between roadway sections. When this principle is violated, the designer needs to intervene and provide additional information to the drivers to assist them in adjusting their speed (Materials *et al.*, 2007a).

In regard to the adoption of design speeds, Krammes (2000) reported that AASHTO's minimum design speeds for arterials on rolling terrain and for collectors on level and rolling terrain underestimated the desired speed of today's drivers. He observed that AASHTO's policy will not guarantee a full compliance between design speed and operating speed if the design speed is less than 62.1 mph. To correct for this discrepancy Fitzpatrick and Carlson (2002) recommended design speed values for rural two-lane highways, which were modified from those recommended by AASHTO. They suggested the use of anticipated operating speed or posted speed plus 10 mph as the design speed (Materials *et al.*, 2007a).

After reviewing the standards of international design speeds for roadway geometric design, Polus observed that the AASHTO design policy controls only the minimum values for design speed and encourages the use of above minimum values. This may currently underestimate the driver's desired speeds. Also, in the classical design speed concept the policies adopted for maximum super elevation rates vary from state to state and from roadway to roadway. These variations might influence driver's speed selection on horizontal curves and may increase the disparity between design and operating speeds. The review also mentioned the standards being adopted in several other countries for roadway design. Germans use both design speed and 85th percentile operating speeds in designing rural roadways. They use design speed as a guiding factor to determine the horizontal and vertical features of an alignment and the 85th percentile operating speed to determine the super elevation rates and stopping sight distances. Swiss engineers use speed profile along an alignment to check for alignment consistency. British designers do not follow the concept of functional classification but they emphasize the effects of alignment and layout (cross-section and access control) constraints while selecting their design speed. Australians use 85th percentile speed as the design speed for low-speed alignment (i.e., less than or equal to 52.5 mph) and traditional design speed procedures in designing their high-speed alignments (i.e., greater than or equal to 62.5 mph). US engineers have a range of design speeds to select among those recommended by AASHTO which are based on functional classification (Materials *et al.*, 2007a).

However, there is a tendency for selecting high speeds, a practice that often disregards driver's desired or operating speeds. Also, AASHTO's policy on design speed selection lacks a feedback loop in which the driver speed behavior resulting from the designed alignment can be estimated and compared with the assumed design speed. In general, every country surveyed uses design speed for its design process and one-third of them use the same procedure for both high-speed and low-speed alignments. The authors concluded that AASHTO should conduct further research on the distribution of driver's desired speeds on rural highways to recommend changes for the suggested minimum design speeds. Research should also be undertaken to fully develop and validate the speed profile procedures for evaluating alignment consistencies (Materials *et al.*, 2007a).

According to Harwood, the under listed four points are a general design procedure that should be followed step wise.

1. Select a design speed first

2. Develop a preliminary design based on the selected design speed

3. Determine the projected operating speed and compare it with the design speed

4. If the operating speed is higher than the design speed, the designer would select a higher design speed and go back to step 2, modify the geometric design, the traffic control plan, and other characteristics of the facility until consistency. If the operating speed is less than or equal to design speed no adjustments are needed and the prepared preliminary design in Step 2 can be further developed.

2.2.1.3 Operational Speed

Krammes (2000) has discussed the use of operating speed as a replacement of the design speed. (The need to reevaluate the use of the design speed as suggested in the Green Book has also been argued and European practices can be used as models. The differences between design and operating speeds were also addressed in Special Report 214, where procedures for addressing this problem were discussed (TRB Special Report, 1987). Disparities between speeds create some of the problems in design consistency and are central to resolving that issue. A recent report that examined the relationship between operating and design speeds for urban areas concluded the use of operating speeds as a controlling design speed produces more consistent designs (Materials *et al.*, 2007a).

A Nebraska study examined the operating speeds at 70 vertical curve sites on horizontal tangents and showed that operating speeds are affected by horizontal curves. The mean, 85th and 95th percentile speeds were used to perform statistical analysis on the collected speed data. At the curve mid-point, the 85th percentile speed decreased by 1 mph for an increase in deflection of 10 degrees. With an increase in deflection of 12 degrees, the 95th percentile speed decreased by 1 mph. This implies the perception that large deflections in horizontal curves are considered to be severe. Also, it was noticed that an increase in the length of the curve resulted in an increase of mean and 85th percentile speed. At the midpoint of the curve, for a 1000 ft. increase in curve length, the 85th percentile speed increased by 4 mph and the 95th percentile speed increased by 3 mph(Materials *et al.*, 2007a). The Highway Capacity Manual (HCM) recommends a process for estimating the free-flow speed of multilane highways based on posted speed limits. However, a recent study indicated that this approach does not adequately estimate the free-flow speed for higher speed limit conditions. The study aimed at developing a correlation between posted speeds and actual field measured free-flow speeds for rural multilane roads. Free-flow speed can be considered as an average travel speed a single vehicle travels with no other vehicles present on the segment of road. A conclusion of the study indicated that free-flow speeds do not seem to affect operating speeds (Materials *et al.*, 2007a).

2.2.1.4 The relation between Speed and Safety

Safety implications due to high speed exist because speeding reduces the available reaction time and could result in a crash. Stuster and Coffman (1998) conducted a synthesis of safety research related to speed and speed management. In this synthesis, they looked at various studies that relate crash rates with change in mean speeds, change in speed at impact and change in posted speed limits and landmark study used 10,000 crashes to examine and define a relationship between vehicle speed and crash incidence on rural highways. A relationship was identified in the form of a U- shape curve between the deviations from the average travel speed and crash rate per 100 million miles. According to this curve, crash rates were lowest when the travel speeds are close to the mean speed of the traffic. However, as the deviation of the travel speed from the mean speed increases in excess of 15 mph, the likelihood of being involved in a crash also increases. One other important observation from this curve is that crash rates decrease with an increase in speed, but this fact only holds good as long as the speed of the vehicle is not above 65mph. Later, Cirillo (1968) confirmed Solomon's research by conducting a similar analysis on 2,000 vehicles involved in daytime crashes on Interstate freeways (Materials *et al.*, 2007a).

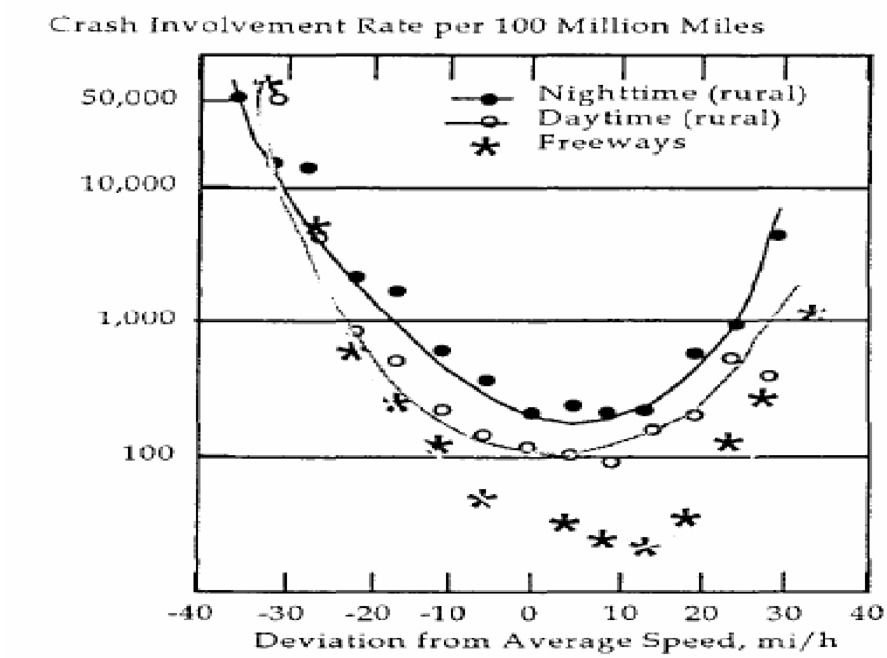

Figure 2.1 Crash Involvement rate by deviation from average travel speed

Source: (Materials *et al.*, 2007a)

Studies have shown that changes in posted speed limits play a minor role in the variation of number of crashes. However, a study by Parker in Michigan examined that the alteration of speed limits on low and moderate speed roads had little effect on crash rates. In another study by Parker, 98 sites in 22 states in the US were considered where speed limits were altered and also showed insignificant figures related to total or injury crashes. On the contrary, after reviewing several international studies, Finch et al. (1994) suggested that for every 1 mph change in mean speed, the number of injury crashes increased by 5 percent (Materials *et al.*, 2007a).

Another element of concern is whether the speed inconsistencies have any safety effect on these roadways. (Materials *et al.*, 2007b) have performed two-step analysis to evaluate the effect of speed inconsistency on road safety:

1. **Crash rate analysis:** This approach calculates the crash rates for each segment examined and compared them to critical rates. This comparison allows for the relative evaluation of the safety level for each segment as compared to the statewide average crash rates for similar sections.

2. **Crash prediction models:** This approach aims to develop a predictive model for determining the impact of design choices on crashes.

They have used Crash data for a three-year period for their analysis. The crashes for each segment for the 2002-2004 period were extracted from the Kentucky crash database based on county, route number, and mile point. Exposure rates were obtained for each site using the site length and the AADT (based on HPMS data). To develop critical rate factors for the first safety analysis, each site was also categorized based on the available critical rates for Kentucky as they had been developed in a previous study (Green et al. 2005). Each segment was identified as a section (if it had length of 0.4 miles or more) or a spot and the corresponding critical rates were identified(Materials *et al.*, 2007a).

The critical rates are computed using the following formula.

$C_c = C_a + K (\text{sqrt} (C_a /M)) + 1/ (2M)$
Where C_c = critical crash rate; C_a = average crash rate; sqrt = square root; K = constant related to level of statistical significance selected (a probability of 0.995 was used where in K = 2.576); M = exposure (for sections, M was in terms of 100 million vehicle-miles (100 MVM); for spots, M was in terms of million vehicles)(Materials *et al.*, 2007a).

To determine the critical rate factors, the actual rate was divided by the critical rate. This returned a ratio that, when greater than one, indicates that the location has a rate that is statistically higher than the statewide average rate for that type of highway. This indicates that the location should be further examined to determine if the presence of any particular elements that could contribute to the crashes at the site. The same procedure was conducted for injury crashes only. A third approach was also utilized where only speed related crashes were examined alone to determine whether there is any pattern that could further explain any safety issues that could arise from the speed inconsistencies(Materials *et al.*, 2007a).

2.2.2 Drainage Structures

The second and main focus area of this research work is investigating effect of drainage structures on road geometric inconsistency. As it has stated above it is not only drainage structures that affect road geometric inconsistency. Roadway lane width, shoulder width, provision of adequate traffic signs, minimum sight distance provided and length of vertical and horizontal curves are some of major issues that may affect road geometry consistency.

Drainage structures can affect road geometry consistency through several ways like by impairing sight distance required a head of driver, forcing drivers to operate with minimum operational speed and by causing vehicle instability. There are no literatures made to show effect of these drainage structures on road consistency. So far most of research papers done on road geometric consistency have considered geometric elements like horizontal curve length and shoulder width to measure consistency. This research presents effect of drainage structures on road consistency in terms of operating speeds, crash rate and ease driving task.

Basically, when we are referring about drainage structures it can be bridge, major culvert (box and slab culvert) or pipe culvert. Only major culverts and bridges are considered in this research. Pipe culverts are not considered because due to less construction cost of these structures roadway geometry will not be compromised on such locations i.e. the road geometry will continue as it was on approaching section. Even in most case these structures are not visible to drivers because there is no any structure constructed above the road surface.

Let us see definitions given to these drainage structures on different national highway design manuals and research papers.

Bridge:

according to Ethiopian roads authority (ERA) the term bridge can be defined as structure including supports erected over a depression or an obstruction, such as water, highway, or railway, having a tract or passageway for carrying traffic or moving loads, and having an opening measured along the center of the roadway of more than six meters between under copings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes. May also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening. Also, a structure designed hydraulically using the principles of open channel flow to operate with a free water surface, but may be inundated under flood conditions(ERA, 2013).

A structure, including supports, erected over a depression or an obstruction, such as water, a highway, or a railway; having a roadway or track for carrying traffic or other moving loads; and having an opening measured along the center of the roadway of more than 20 feet between faces of abutments, spring lines of arches, or extreme ends of the openings for multiple box culverts or multiple pipes that are 60 inches or more in diameter and that have a clear distance between openings of less than half of the smallest pipe diameter(AASHTO, 2004).

Bridges are structures usually constructed in-place (although pre- manufactured elements are commonly used) which carry traffic directly on a deck surface. Bridges do not form inlet conditions or act as pressurized conduits since the flow line of a bridge is rarely fixed and the material along the flow line of a bridge is usually the same as the stream it crosses(Mass- Highway, 2006).

Culvert:

A structure that is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity. A structure used to convey surface runoff through embankments. A structure, as distinguished from bridges, that is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. Also, a structure which is six meters or less in centerline length between extreme ends of openings for multiple boxes(ERA, 2013).

Culverts are usually pre-manufactured sections that can operate either with a submerged inlet (under pressure) or with free surface flow. The roadway cross-section is usually constructed on fill placed over the culvert. Culverts exceeding 20 feet in length along the roadway centerline are classified as bridges; however, despite this classification culvert design standards should be followed(Mass- Highway, 2006).

2.2.2.1 Road Geometry and Drainage structures

The designer shall ensure that the bridge deck will freely drain water to minimize gutter spread or ponding. This is normally accomplished by some combination of the bridge cross-slope, bridge profile and openings in either the deck or the barrier that allows the water to flow off the bridge. Location of the low-point of a vertical curve on a bridge or approach slab is strongly discouraged, and should only be considered when there is no feasible alternative. Before proceeding with a design that has a low point on a bridge or approach slab, the designer should consult with the roadway designer and then the Bridge Office to confirm that no other feasible option exists. When a low-point is located on a bridge, it shall not be located within 10 feet of the BFPR or centerline of bent, and scupper spacing shall be reduced to 2'-6" within 10 feet of the low point.

If the bridge grade is less than 0.5%, the designer should consult with the roadway designer about increasing the grade to provide more efficient drainage(State of Georgia, 2015).

The process of designing a stream crossing system requires a comprehensive engineering approach that includes formulation of alternatives, data collection, selection of the most cost-effective alternative according to established criteria, and documentation of the final design (ERA Drainage Design manual,2001).

Bridges are highly visible elements of the transportation infrastructure in the surrounding landscape. Often, they traverse environmentally and ecologically sensitive sites, culturally or visually significant areas, or are visually prominent features in communities and other developed settings. Although bridges can have negative impacts on these environments, they can also be designed in such a way that they are pleasing or welcome additions to the landscape.

Designing a suitable bridge requires that the designer to pay careful attention to the details starting with an understanding of the setting in which the structure will be built and ending with the detailing of the bridge structure itself. Bridges can be designed to blend into the surrounding natural or built environment, if that is what is desired. Alternatively, bridges can serve as signature elements of the community by standing out from their surroundings. In either case, the designer must remember that the bridge can last many decades. The role of the bridge in the built environment should be determined during the project development process with input from a broad range of interested individuals and groups. In doing the above responsibilities the design Engineer should pay a greater attention for safety requirement of bridge design(Mass- Highway, 2006).

It is desirable that bridges to be located on tangent locations of the alignment. But sometimes it is necessary to locate a bridge on a curve. When this happens, care should be used to avoid beginning or ending a curve on the bridge. This can be hazardous under slippery surface conditions and also adds complications to bridge design and construction. When curves are necessary on road sections near bridge ends, the beginnings and endings of curves should be located so that no portion of the super elevation transition extends onto the bridge.

The last sentence of the above paragraph seems to conflict with safety criteria of roads. This is because a driver operating within horizontal curve section expects that geometric elements of the curve will continue the same until the curve ends. Therefore, removal of supper elevation on bridges located within supper elevated horizontal curve will make driving task difficult by forcing the driver to change abruptly his/her driving characteristics. Which consequently affects the highway geometric consistency.

Bridge structures should be on a tangent alignment if such can be accomplished without sacrificing the overall geometric design of the highway. Tangent alignment affords easier plan preparation and easier bridge construction thereby resulting in lower structure cost. In areas where it is not feasible to build structures on a tangent alignment, curved structures are possible. Where curved structures are built, their geometry should fit the curve geometry for the roadway sections. Tightly curved alignments can significantly restrict the type of superstructure(Mass- Highway, 2006).

The vertical curvature of structures should generally conform to curvatures on sections of roadway for the same conditions of traffic and terrain type recommended by the design manual. For bridge decks that would otherwise be flat, a small crest vertical curve is recommended throughout the bridge length to prevent an illusion of sag and to improve deck drainage(Mass- Highway, 2006).

For any crossing structure, a constant clear roadway width and a uniform protective railing or parapet should be provided. The multimodal accommodation and cross-section features found along the adjacent roadway segments should be included on the bridge cross-section. It is not usually necessary for the bridge deck to be substantially wider than the approaching roadway but the design of the bridge structure should include consideration of possible future widening such as by providing a wider abutment. Generally, the width of the travel way and shoulder lanes should be consistent with the existing or planned future cross section of the adjacent roadway. In terms of additional width, a 2-foot setback from the shoulder or bike lane to bridge rails or parapet walls is required. Additionally, or alternatively, approximately 1 to 2 feet of additional sidewalk width is desirable to account for shy distance from the railing or parapet wall when sidewalks are provided(Mass- Highway, 2006).

Even if the main objective of providing bridges and culverts is to assure safe passage of flood across a road, it is very crucial to pay a greater consideration for road safety aspect on drainage structures. This is because bridge and culvert geometrical characteristics like, width, Reduced level and location have significant influence on the road performance. Ethiopian Road Authority's manual for design of drainage structures state points that should be considered as principles while designing culverts and bridges. The following are some of these guiding points stated on drainage design manual.

- All culverts shall be hydraulically designed.
- Overtopping flood selected is generally consistent with the class of highway and the risk at the site.
- Survey information shall include topographic features, channel characteristics, highwater information, existing structures, and other related site-specific information.
- Culvert location in both plan and profile shall be investigated to avoid sediment build-up in culvert barrels.
- Culverts shall be designed to accommodate debris or proper provisions shall be made for debris maintenance.

The type of drainage structure specified for a particular location is often determined based on economic considerations. Bridges are used where they are more economical than a culvert, perhaps due to the need to bury a culvert under a high level of fill. They are also employed to satisfy land use requirements, to mitigate environmental harm possible with a culvert, to avoid floodway or irrigation canal encroachments, and to accommodate large debris.

Culverts are used where bridges are not hydraulically required, where debris is tolerable, and where they are more economical than a bridge. Culverts can be concrete box culverts, reinforced concrete pipe culverts, or corrugated metal culverts.

Concrete box culverts are constructed with a square or rectangular opening, and with wingwalls at both ends. They are usually specified for larger flows, where the area of the opening is larger than that available for manufactured concrete or metal pipe culverts. They may also be used where the cost estimate indicates that concrete box culverts constructed on site are less expensive than manufactured and/or imported pipe culverts. An alternative sometimes employed is to use metal arch pipe, and for larger openings this can be more economic than concrete.

Although metal pipe culverts are usually less expensive than concrete pipe culverts, a cost estimate may indicate that this is not the case. There are local concrete pipe culvert manufacturers producing pipe of varying quality; presently all metal pipes need to be imported (ERA Drainage design manual,2001).

On the other hand, AASHTO bridge design specification report states that the choice of location of bridges shall be supported by analyses of alternatives with consideration given to economic, engineering, social, and environmental concerns as well as costs of maintenance and inspection associated with the structures. The location and the alignment of the bridge should be selected to satisfy both on-bridge and under-bridge traffic requirements. Consideration should be given to possible future variations in alignment or width of the waterway, highway, or railway spanned by the bridge.

According to this report attention should be taken in selecting bridge locations that should meet the under listed criterions.

- Fit the conditions created by the obstacle being crossed;
- Facilitate practical cost-effective design, construction, operation, inspection and maintenance;
- Provide for the desired level of traffic service and safety; and
- Minimize adverse highway impacts.

Although the location of a bridge structure over a waterway is usually determined by other considerations than the hazards of vessel collision, the following preferences should be considered where possible and practical:

- Locating the bridge away from bends in the navigation channel. The distance to the bridge should be such that vessels can line up before passing the bridge, usually eight times the length of the vessel. This distance should be increased further where high currents and winds are prevalent at the site.
- Crossing the navigation channel near right angles and symmetrically with respect to the navigation channel.
- Providing an adequate distance from locations with congested navigation, vessel berthing maneuvers or other navigation problems.
- Locating the bridge where the waterway is shallow or narrow and the bridge piers could be located out of vessel reach.

The bridge width shall not be less than that of the approach roadway section, including shoulders or curbs, gutters, and sidewalks. No object on or under a bridge, other than a barrier, should be located closer than 4.0 ft. to the edge of a designated traffic lane. The inside face of a barrier should not be closer than 2.0 ft. to either the face of the object or the edge of a designated traffic lane. The specified minimum distances between the edge of the traffic lane and fixed object are intended to prevent collision with slightly errant vehicles and those carrying wide loads(Customary U.S Units, 2012).

Constraints due to bridges can have a significant impact on road geometry. These constraints can be much more restrictive than normal roadway geometric design criteria. Identification of potential bridge constraints and accounting for them during geometric layout of the road is often the most cost-effective method of optimizing the overall project.

Potential impacts of bridges on roadway geometry include:

- Bridge rails can impact the horizontal stopping sight distance: Solutions include tangent alignment on bridge, increased curve radius across bridge, and wider shoulder at the inside of the curve.

- Bridge rails can impact vertical intersection sight distance for ramps at grade separations: Solutions include increased K value for vertical curves, longer offset to ramps/intersection from bridge end, and wider shoulders.
- Bridge barriers and raised medians can impair lateral deck drainage, resulting in pooling and encroachment onto driving lanes: Solutions include increased longitudinal grade, wider shoulders and reduced contributing drainage area (e.g. drain sidewalks separately).

Bridge costs and complexity of design increase rapidly with increased skew angle beyond 25 – 30 degrees. Therefore, modifying alignment to reduce the skew to less than 30 degrees, where feasible minimizes design complexity and cost of bridges. Bridge costs and complexity of design can increase significantly with slight changes in alignment at river crossings. Locating crossing on a relatively narrow section of stable channel with a low skew, where feasible will be solution for such challenges. Potential impacts on river protection works, channel modifications, and environmental requirements should be assessed before finalizing the road alignment. River crossing bridges can also have significant impacts on minimum road grade lines due to freeboard and structure depth requirements combined with minimum desirable grade.

The clear width for all new bridges on urban collector streets with curbed approaches should be the same as the curb-to-curb width of the approaches. The bridge rail should be placed flush with the front face of the curb if no sidewalk is present to minimize the likelihood that vehicles will vault the rail. For urban collector streets with shoulders and no curbs, the full width of approach roadways should preferably be extended across bridges. Sidewalks on the approaches should be extended across all new structures. In addition, a sidewalk should be included on at least one side on all bridges on collector streets.

The design of bridges, culverts, walls, tunnels, and other structures should be in accordance with the current AASHTO Standard Specifications for Highway Bridges, or with the AASHTO LRFD Bridge Design Specification. Except as otherwise indicated herein, the dimensional design of structures should also be in accordance with these standard specifications. Accordingly, AASHTO geometric design manual provides minimum clear roadway width for drainage structures that have constructed newly and for those which remains in place during road improvement. In both case clear roadway width is a function of traffic volume.

The bridge length is mostly determined by the obstacle that the bridge must span. For nearly all road projects the obstacle falls within two general categories – Bodies of Water (Stream Crossings) or Travel ways (Grade Separations). Bridge spans over roads or railroads shall be long enough to span the travel way, drainage ditches, shoulders, sidewalks, clear zone for the travel way, and the offset distance from the toe of slope paving or face of abutment wall(State of Georgia, 2015).

The tables below show recommended minimum roadway clear width for both new and existing drainage structures with traffic volume. But, these values are applicable only for rural roads.

Table 2.4 Minimum Roadway Widths and Design Loadings for New and Reconstructed Bridges

Metric		US Customary	
Design Volume(Veh/day)	***Minimum roadway width for Bridges***	***Design volume (Veh/day)***	***Minimum clear roadway width for Bridge***
400 and under	Traveled way + 0.6m (each side)	400 and under	Traveled way + 2ft (each side)
400 to 1500	Traveled way + 1m (each side)	400 to 1500	Traveled way + 3ft (each side)
1500 to 2000	Traveled way + 1.2m (each side)	1500 to 2000	Traveled way + 4ft (each side)
Over 2000	Approach roadway width	Over 2000	Approach roadway width

- *Where approach roadway width (Traveled way plus shoulder) is surfaced, that surfaced width should be carried across the structures.*
- *For Bridges in excess of 30m in length, the minimum width of traveled way plus 1m on each side is acceptable.*

Source: AASHTO Geometric design manual, 2001

For Bridges and culverts to be Remain in Place, because highway geometric and roadway improvements may encourage higher speeds and attract larger vehicles, existing structures also should be improved correspondingly. Because of their high cost, reasonably adequate bridges and culverts that meet tolerable criteria may be retained.

Where an existing highway is to be reconstructed, an existing bridge that fits the proposed alignment and profile may remain in place when its structural capacity in terms of design loading and roadway width are at least equal to the values shown for the applicable traffic volume in the table below.

Table 2.5 Structural Capacities and Minimum Roadway Widths for Bridges to Remain in Place

Metric			US Customary		
Design volume (veh/day)	Design loading structural capacity	Minimum clear roadway width (m)[a]	Design volume (veh/day)	Design loading structural capacity	Minimum clear roadway width (ft)[a]
under 400	MS 13.5	6.6	under 400	H 15	22
400 to 1500	MS 13.5	6.6	400 to 1500	H 15	22
1500 to 2000	MS 13.5	7.2	1500 to 2000	H 15	24
over 2000	MS 13.5	8.4	over 2000	H 15	28

[a] Clear width between curbs or railings, whichever is less, should be equal to or greater than the approach traveled way width, wherever practical.

Source: AASHTO Geometric design manual, 2001

The values in the above table do not apply to structures with a total length greater than 30 m [100 ft.]. Such structures should be analyzed individually by taking into consideration the clear width provided, crash history, traffic volumes, remaining life of the structure, design speed, and other pertinent factors (AASHTO Geometric design manual, 2001).

Consideration shall be given to safe passage of vehicles on or under a bridge. The hazard to errant vehicles within the clear zone should be minimized by locating obstacles at a safe distance from the travel lanes.

According to ERA highway geometric design manual, the width of bridges should correspond with the clear roadway or carriageway width as determined according to Geometric Design Manual. The width is to be measured between the inside of the railings − or the curbs. Clear width of bridge is defined as the distance between the inside of the outer railings including walkways, island/refuge and similar. If the width will vary along the bridge all dimensions should be given and meet minimum width requirements.

If not otherwise stated in the ERA Geometric Design Manual, a one-lane bridge shall not be less than 4.2 m wide and a two-lane bridge not less than 7.0 m wide. The dimensions for a one-lane bridge are based on the current ERA standard Bailey bridge width used for one-lane road. The dimensions of 7.30m for a two-lane bridge are based on trucks with widths of 2.4m meeting, providing 0.7m clearance between vehicles and at the sides, the greater clearance allowing a higher average speed.

At higher design speed, and/or in the vicinity of densely populated areas, a bridge allowing for the shoulder width should be considered. Here the bridge width becomes 10.30 meters (7.30 meters plus 2 x 1.5 shoulders or sidewalks). This allows for opposing trucks and pedestrians to meet safely. This width is recommended for bridges nearer than 5 km to a town/village of at least 10,000 inhabitants. All dimensions are valid regardless of the length of the bridge, due to safety reasons.

Table 2.6 Recommended Bridge Widths for different road types

Application	Width(m)
Two-lane in 'urban' Area	10.30
Two-lane in 'Rural' Area	7.30
Single lane	4.20
Pedestrian Overpasses	3.0

Source: ERA Design manual 2002

According to Transportation Association of Canada 1999 & British Columbia Ministry of Transportation 2007a, bridges on rural roads are often two-way, single lane, crossings with approach alignment designed to a less conservative standard than highway standards. Canadian Standards Association 2006 states that Preference shall be given to straight horizontal alignments for bridges. The bridge deck longitudinal profile shall be continuous with the approach road profile. However, due to rugged and varied terrain conditions it is not always practical to plan for long horizontal and vertical tangents; geology, site conditions, and economics often result in roads being narrow and (or) having sharp curves adjacent to bridge structures. In these situations, it is important that a team of qualified professionals use all relevant planning tools to design a crossing. Planning tools should account for user safety, design vehicle geometry, and crossing lifespan.

While current design manuals provide some guidance on these subjects, in many parts of the province, alignment is based solely on experience or site conditions. The resulting use of rules of thumb or best fit approaches has led to a lack of design consistency (that is, a mix of approaches and methods are being used across the province). FLNRO's Engineering Manual (Engineering Branch 2013) recommends minimal horizontal and vertical tangents of 15 m, while FLNRO (Engineering Branch 1999) recommends 10 m. The United States Forest Service (2014b) recommends minimum horizontal approach tangents of 100 ft. (30.5 m) and 50 ft. (15.2 m), depending on road use. The Geometric Design Guide for Canadian Roads (Transportation Association of Canada 1999) is more applicable to highway bridges because it specifies approach alignment in context of super elevation, which is not common when designing rural roads, and does not provide specific tangent distances. British Columbia Ministry of Transportation 2007a also recommends that bridges be located outside of curves, with an appropriate tangent but, again, does not specify a tangent distance and, in any case, is referring to highway bridges. This lack of standardization for designing bridge approaches on rural roads results in lack of geometric design consistency which potentially produces unsafe driving environment for user and increased repair and maintenance costs to bridges across national road networks.

Bridge approach design is an iterative process that incorporates detailed field assessments with office based analysis and computer-aided design (CAD) to determine the most suitable bridge alignment. For bridges on rural roads, the design is typically carried out by a consulting engineer. The design process begins with field technicians performing site reconnaissance, layout, and surveys, followed by the design which is certified by an Engineer of Record. The entire process is managed by a Coordinating Registered Professional who, depending on scope of practice, is responsible for issuing a crossing assurance statement, and ensuring all elements of the crossing design and construction are safe and comply with current legislation.

Table 2.7 below summarizes the results of evaluating minimum required bridge widths for each design vehicle. It was found that smaller curve radii and larger curve paths required wider bridge widths. This was common for all Auto TURN simulations. FLNRO standard bridge deck widths are specified to be 4269 mm and 4877 mm wide, with guardrails typically mounted to the outside of the bridge deck. 168 Auto TURN simulations were performed using the various vehicle configurations, curve radii, curve paths and standard approach tangents. Of the results 89 indicated that a bridge width of 4269 was too narrow, and for 42, a bridge width of 4877 mm was too narrow. As would be expected, the severity increases with smaller curve radius and degree of approach road curve. This illustrates the importance of applying higher level engineering and the value of identifying standard vehicle configurations for bridge approach road design. It is suggested that FLNRO undertake a review of its standards for bridge deck widths in relation with bridge approach road tangent lengths (Alexander Forester, 2013).

Table 2.7 Minimum bridge widths for a range of common bride approach curves and design vehicles.

Design Vehicle	Tangent Length (m)	**Minimum Bridge width (m)**											
		45^0 approach curves			90^0 approach curves			135^0 approach curve			180^0 approach curve		
		15m radius curve	35m radius curve	100m Radius curve	15m radius curve	35m radius curve	100m Radius curve	15m radius curve	35m radius curve	100m Radius curve	15m radius curve	35m radius curve	100m Radius curve
Long- Load Logging Trucks (LLT)													
LLT	10	4.42	3.98	3.75	4.80	4.02	3.62	4.97	4.02	3.63	5.02	4.02	3.62
	15	4.05	3.76	3.63	4.27	3.78	3.53	4.37	3.77	3.54	4.40	3.78	3.53
5-Axle off Highway Logging Truck (L series)													
L-100	10	4.67	4.36	4.24	4.87	4.38	4.13	4.92	4.38	4.14	4.95	4.38	4.13
	15	4.39	4.20	4.14	4.48	4.21	4.07	4.52	4.21	4.08	4.52	4.21	4.07
L-150	10	4.68	4.36	4.24	4.86	4.37	4.13	4.93	4.37	4.14	4.94	4.37	4.35
	15	4.38	4.20	4.14	4.49	4.21	4.07	4.52	4.21	4.08	4.53	4.21	4.07
L-165	10	4.61	4.32	4.22	4.76	4.33	4.12	4.82	4.33	4.13	4.82	4.34	4.12
	15	4.33	4.71	4.12	4.42	4.18	4.06	4.44	4.18	4.07	4.45	4.18	4.06
Tractor/Semitrailer combination (WB Series vehicles)													
WB-19	10	4.71	4.22	3.90	5.36	4.34	3.73	5.74	4.36	3.75	5.93	4.36	3.73
	15	4.33	3.98	3.75	4.78	4.06	3.63	5.04	4.06	3.64	5.16	4.07	3.63
WB-20	10	4.80	4.28	3.93	5.51	4.42	3.75	5.93	4.44	3.77	6.19	4.44	3.76
	15	4.40	4.03	3.78	4.88	4.12	3.65	5.18	4.12	3.67	5.34	4.12	3.65
Tractor/Low bed trailer													
Tridem/ Tridem low bed	10	5.22	4.77	4.46	5.91	4.90	4.32	6.34	4.91	4.34	6.58	4.92	4.32
	15	4.88	4.56	4.34	5.33	4.64	4.22	5.59	4.65	4.24	5.83	4.65	4.22

Source: Alexander Forrester, 2013

2.2.2.2 Bridge and Culvert related crashes

While the African Region possesses only 2% of the world's vehicles it contributes 16% to the global deaths. Nigeria and South Africa have the highest fatality rates (33.7 and 31.9 deaths per 100,000 population per year, respectively) in the region. More than one in four deaths in the African Region occur on Nigeria's roads, and with six other countries; Democratic Republic of Congo (DRC), Ethiopia, Kenya, South Africa, Tanzania, and Uganda, are responsible for 64% of all road deaths in the region (Road Safety Facts in the African Region, 2013).

The above stated fatality rate indicates that Ethiopia is one of the leading country in its traffic based fatality rate in the world and even it is one out of the six leading countries in Africa in terms of traffic accident rate. Even if there are a number of contributing factors for traffic accident fatality rate, failure in designing roads that do not force drivers to make abrupt changes in their driving character is the major cause especially in developing countries like Ethiopia.

While very little statistical data of accidents on bridges have been collected, vehicles on bridges are more vulnerable to the cross gusts than on roads. The reasons include that many vehicles experience a suddenly strengthened crosswind when they just enter the bridge that is usually more open than the road. This is especially true when compared with roads with trees, hills or bushes on both sides. To reduce accidents, some safety measures like setting an appropriate driving speed limit and criteria to close the bridge/highway during windy period have been adopted. However, in the past, the decision of setting driving speed limit and closing the transportation on bridges and highways is mostly based on intuition or subjective experience. The driving speed limit could be too high to be safe or too low to be efficient(Chen and Cai, 2004).

Crash rates were highest for bridges with lower traffic volumes, narrower widths, and negative relative bridge widths (relative bridge width is defined as: bridge width minus roadway width). Crash rate did not appear to be effected by bridge length. Statistical analysis confirmed that the frequency of vehicle crashes was higher on bridges with a lower width compared to the roadway width.

Bridge rail and approach guardrails provide safety to drivers by shielding more hazardous objects and redirecting vehicles to the roadway. However, guardrail can increase both the initial cost and maintenance cost of a bridge, while adding another object that may be struck by vehicles. Bridge rails should always be designed in accordance with the latest available standards on newly constructed bridges. For existing bridges being rehabilitated using federal-aid money the bridge rail should be reviewed for possible retrofitting.

According to a study report of Hans and Zachary (2010), an approach guardrail should be installed in the following situations:

- All four bridge corners on newly constructed bridges on the Farm-to-Market systems, except bridges located within an established speed zone of 35 mph or less.
- On the approach bridge corners (right side) on new federally funded bridges constructed on the area service system, except bridges within 35 mph or less speed zone. Consideration should be given to shielding the opposite corner if it is located on the outside edge of a curve.

- Culverts with spans greater than six feet (circular pipe culverts greater than 72" in diameter) if it is impractical to extend beyond the clear zone and grates are not utilized.

On the other hand, the following exceptions apply when approach guardrail is not needed on a bridge:

i. Current ADT at structure is less than 200 vehicles per day.
ii. The structure is 24 ft. wide or greater.
iii. The structure is on tangent alignment.
iv. The benefit-cost ratio is less than 0.80.

At a time of rehabilitating or constructing a new bridge there may be a need to upgrade bridge approach handrail. Bridge Rail Rating System matrix can be used to determine if a bridge rail should be upgraded or not and to what extent it should be upgraded. The matrix includes five factors: crashes, ADT, width, length, and type of bridge rail. The sum of the points from the five factors is the total bridge score which can be used to determine if the bridge needs upgrading; the higher the score the more upgrade needed(Zachary & Hans, 2010).

Tables below show these bridge rails rating system, points associated with each factor and recommended upgrades based on point totals.

Table 2.8 Bridge rail five factor rating system

Points	**0**	**5**	**10**	**15**	**20**
Factors			**Description**		
Crashes (in last 5 years)	None	1 PDO	1 PI	1 F or 2 PDO's or 1 PI and 1 PDO	2 or more F's/PI's or 3 or more PDO's
ADT (current year)	< 200	200-299	300-399	400-750	>750
Bridge Width (feet)	≥ 30	28	24	22	≤ 20
Bridge Length (feet)	< 50	50-99	100-149	150-200	>200
Bridge Rail (type)	Aluminum Rail (1967 standard)	Steel Box Rail (1964 standard)	Formed Steel Beam Rail (1951 and 1957 standards)	Steel Rail (1941 standard Concrete Rail 1928 standard)	Angel Handrail (1928 standard)

Source: (Zachary & Hans, 2010)

Abbreviations:

PDO = Property Damage Only crash

PI = Personal Injury crash

F = Fatality crash

Table 2.9 Bridge rail upgrades based on point totals

Point total	Upgrade Description
Under 25 points	No upgrading at this time
25 – 50 points	Delineation according to standard RE-48A
51 – 75 points	Block out with thrie beam to curb edge (if existing approach guardrail is W-beam, W beam may be used)
Over 75 points	Retrofit

Source: (Zachary & Hans, 2010)

The geometric design guide does not contain specific information on bridge and approach guardrail, but instead emphasizes roadway cross-sections, bridge widths, alignment, and sight distance characteristics. The guide indicates that bridge widths for newly constructed bridges on new roadways should be equal to the width of the traveled way plus 2 ft. If the roadway is paved, the bridge width is recommended to be equal to the roadway width. For one and two-lane roads with ADT less than 100 vehicles per day, one lane bridges can be provided. A minimum bridge width of 15 ft., but not wider than 16ft assures drivers will not try to use them as two lanes. When existing bridges are being replaced, and there is no evidence of site-specific safety problems, the new bridge width can be the same as the existing width. Site-specific safety indicators include a documented crash history, skid marks, damage to bridge rail or approach rail, and concerns raised by law enforcement officials(Zachary & Hans, 2010).

Hans and Zachary had also carried out analysis on the frequency of traffic crash on road side/bridge handrails versus approach guardrails. Accordingly, collisions with the roadside or bridge rail end are approximately 2.5 times more likely to result in fatalities or incapacitating injury (injury type-A) versus collisions with approach guardrail. Also, guardrail crashes are nearly twice as likely to result in no injuries versus roadside or bridge rail crashes.

Table 2.10 Probability of crash severity versus object struck from logistic regression

	Probability of a Given Crash Severity Based on the Object Struck		
Severity (based on KABCO scale)	**Roadside**	**Bridge Rail**	**Guardrail**
Property damage only	0.337	0.299	0.586
B-injuries/C-injuries	0.451	0.458	0.326
Fatalities/A-injuries	0.213	0.243	0.088

Source: (Zachary & Hans, 2010)

Two-way Pearson chi-square analysis that was performed to show chance experiencing fatal injuries out of the total injuries faced on crashes with road side objects, bridge rails and approach guardrail. On their study Hans and Zachary have shown that zero of the 33 crashes with approach guardrail resulted in fatalities or A-injuries, while roughly one-quarter of the 63 roadside and bridge rail crashes resulted in fatalities or A-injuries. Like the logistic regression analysis, the chi-square test showed that crashes with the approach guardrail were much more likely to result in no injury versus roadside or bridge rail crashes. It appears that the crash severity is significantly affected by the type of object struck in the collision.

The chi-square analysis of object struck vs. guardrail presence showed that the presence of a guardrail did have an effect on the type of objects struck. In crashes at bridges without approach guardrail about 70 percent of the crashes were collisions with the bridge rail. Of the crashes at bridges with approach guardrail about 6 percent were collisions with the bridge rail. The chi-square analysis confirmed that crashes at bridges with approach guardrail were significantly less severe than crashes at bridges without approach guardrail. The percentage of fatality/A-injury crashes at bridges without approach guardrail was 4.5 greater than the percentage of fatality/A- injury crashes at bridges with approach guardrails(Zachary & Hans, 2010).

Crashes at bridges and culverts include those involving vehicles (or pedestrians, cyclists, etc.) travelling over the bridge or culvert, under the bridge, or on the approaches to the bridge or culvert. Brides and culverts are inherently hazardous because their abutments, railings or piers intrude into at least the road side, and often into the shoulders of the road; in some cases, they also intrude into the normal lane width. It is clear that the great majority of bridges would have their end posts and railings within the desirable clear zone, and that the bridge piers of many over bridges would also be within that zone. Similarly, the end walls of many culverts would also be within the desirable clear zone(OGDEN, 1989).

Graham, reported that this inherent hazard of bridges is reflected in bridge piers and end posts having the highest severity index of all road side hazards in the Road Construction Authority's road side hazard program. Similarly, bridges had the highest accident severity rating of all road side hazards in the study undertaken for the Road Traffic Authority by Pak Poy and Kneebone Pty Ltd. According to this study accident severity was defined as the ratio of fatal plus personal injury accidents to total accidents happened(OGDEN, 1989).

A major study conducted as part of the US National Cooperative Highway Research Program attempted to define a narrow bridge. Based on studies of driver behavior at bridges and bridge crash records, the study concluded that:

a. Any bridge less than 7.3m wide should be considered as a restricted-width bridge, but not necessarily a hazardous bridge site.
b. Any bridge less than 5.5m in width should be considered a one-lane bridge.
c. Any bridge with a width of 4.5m or less should be considered a hazardous site.

Crashes at bridges and culverts have been found in various studies to be a significant proportion of total road crashes, especially in rural areas. A study by Hollingsworth based on data for Queensland road in the late 1970s found that bridges and culverts were associated with slightly less than 10% of road injury. However, he noted that these structures (Bridges and culverts) represent less than 0.5% of the total length of the Queensland road network, it becomes obvious that culverts and bridges contribute an inordinate contribution to the annual road crash injury.

Building on results of this sort, the 1984 NAASRA Roads Authority Study (NAASRA, 1984) claimed that it has been established that bridges and culverts make an inordinate contribution to road accidents on a length basis compared to other section of the roads generally. This report pushes to develop ideal bridge width requirements in relation to traffic flow which is indicted on the table below.

An American study (Pigman, Agent and Zegeer, 1981) based on all reported crashes in the state of Kentucky found that crashes at bridges and culverts constituted 11.1% of total. Crash rates in terms of the number of crashes per 100 million vehicles using the bridge were calculated as:

- 11.2 for large urban areas
- 11.8 for medium urban areas, and
- 15.5 for rural areas.

Another US study surveyed 40 states and 17 local government agencies, asking, inter alia, for details of specific hazardous highway elements within their respective jurisdictions. The most frequently cited element by far was narrow bridge and culvert, abutments, piers, bridge approaches. This was stated by 27 states and 5 local government agency respondents, and the total of 32 respondents was more than twice that for the next most cited element (guard rail deficiencies, at 15 respondents).

2.2.2.3 Crash types associated with Bridges and Culverts

In general, crashes at bridges and culverts may be divided into three categories according to (King, 1978) and (Hollingsworth, 1983).

- Vehicle collision with bridge or culvert (end posts, railings and pier) or its approaches,
- Collision between vehicles, due to presence of culvert or bridge i.e. lateral position of vehicles, visibility restrictions due to road or bridge geometry.
- Collisions near the bridges and culverts, where presence of culverts and bridges is not a contributing factor. For example, Hollingsworth, 1983 stated that one third of all crash injuries reported in the 1978-79 bridge crash summery was totally unrelated to culvert or bridge involvement; in most cases, such crashes had merely occurred in the general vicinity of such structures(OGDEN, 1989).

The above stated of Hollingsworth's study on crash rates on bridges and culverts shows that crash types on such structures can be classified as single vehicle collides with fixed object, single vehicle overturned, rear end collision, side sweep in opposite direction, head on collision and others. Accordingly, he has listed these crash types in order of increasing their occurrence rate he has observed on the Queensland road section as shown below.

Table 2.11 Crash types on bridges with observed frequency of occurrence

Single vehicle collided with fixed object	244
Single vehicle overturned	102
Rear end collision	93
Side swipe towards opposite direction	53
Head on collision	50
others	41

Source: Ogden, Crash at Bridge and culverts, 1989

He has also ordered crash types based on the number of severe injuries and fatalities faced on total crashes occurred.

Table 2.12 Crash types with frequency of experiencing severe injury of fatalities

Single vehicle collided with fixed object	183
Single vehicle overturned	68
Rear end collision	68
Side swipe towards opposite direction	31
Head on collision	26
others	27

Source: Ogden, Crash at Bridge and culverts, 1989

From the data above, it can be seen that the same crash types were involved for both cases except a little offset between their order. To get further information on the effect of bridge width on crash rate and severity, the top three crash types in the above group of crashes were examined in detail. As an illustration crash data for single vehicle collide with fixed object has shown below.

Table 2.13 Distribution of single vehicle collision crash rate per location on bridge & culverts and accident types

Crash location on bridge and Culverts	% of total crashes occurred	% of total serious injuries & fatalities
Approach guard rail	6.6	3.2
Bridge end points	16.7	36
Bridge rail	36.7	19.4
All others	40	41.4

Source: Ogden, Crash at Bridge and culverts, 1989

2.2.2.4 Bridge and Culvert Crash prediction models

Various attempts were made model for estimating crash frequencies related to bridge and culverts in relation to bride and culvert widths and road geometry.

Ivey (1979) developed a so-called bridge safety index (BSI), based on crash data for a sample of bridges in Texas. In this study, a range of 10 factors were considered which are listed below.

- Bridge width factor
- Relative bridge width (bridge lane: approach lane width)
- Guard rail and bridge rail factor
- Approaching sight distance factor
- Distance from bridge to end of adjacent horizontal curve.
- Grade continuity factor
- Shoulder reduction factor
- Volume to capacity ratio for the road.
- Traffic composition factor
- Distractions and road side activities factor

The above stated factors are a mixture of subjective variables, it need an assessment of adequacy of guard fences and bridge railing, quantifiable variables like dimensions of bridges and culverts. As a result, models developed from values of this factors will be empirical; it would be difficult to apply for practical purpose.

Hollingsworth (1983) developed a series of equations for crashes at bridges on his Queensland study. Because his data did not allow individual bridge sites to be identified, data unique to that bridge could not be used. Thus, he based his analysis on data for road sections, each section comprising the length of a given road in single local government area. Low standard roads were excluded by including only roads with design speed of 72 km/h or greater, and bridge with data for all bridges in the rod section were extracted. These were used as surrogate measures of bridge width to test for bridge width-crash rate relationships.

Table 2.14 Traffic volume criteria for bridge widths- Australian case

Bridge width (m) (between Kerbs)	**Quality of service for traffic flow (veh/d)**		
	poor	**Fair**	**Good**
Under 4.9	>100	61-100	<60
5.0-5.9	>300	151-300	<150
6.0-6.9	>4000	1001-4000	<1000
7.0-7.9	>6000	4001-6000	<4000
>7.9			all

Source: National Association of Australian State Road Authorities, 1984

Table 2.15 Crash frequency verses bridge/ culvert width for different road classes-Victorian case

Road category and width	**Quality of service**			**Road category and width**	**Quality of service**		
	poor	**Fair**	**Good**		**poor**	**Fair**	**Good**
National highways (127 bridges)				***Secondary arterials (955 bridge)***			
6.0-6.9	Up to 4.9	9	7	Up to 4.9	9	7	0
7.0-7.9	5.0-5.9	39	10	5.0-5.9	39	10	8
Over 7.9	6.0-6.9	8	61	6.0-6.9	8	61	206
Primary arterials (447 bridges)				7.0-7.9	2	0	280
Up to 4.9	Over 7.9			Over 7.9			325
5.0-5.9	6	0	0	***All rural arterials (1529 bridges)***			
6.0-6.9	4	26	30	Up to 4.9	11	7	0
7.0-7.9	4	3	71	5.0-5.9	45	10	8
Over 7.9	0	0	301	6.0-6.9	13	87	236
				7.0-7.9	7	5	355
				Over 7.9	0	0	745

Source: road construction authority (1984)

Chapter 3 Methodology

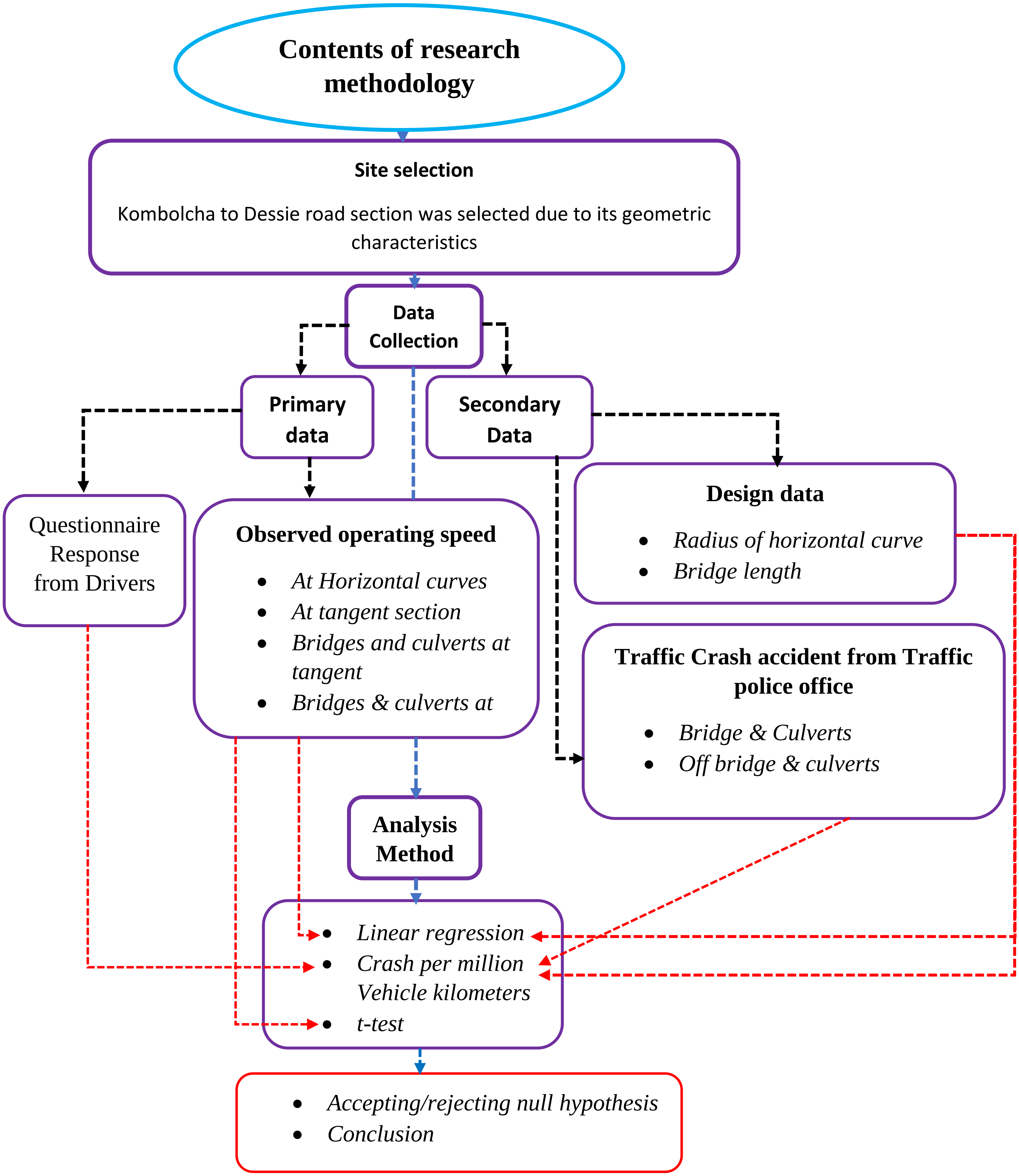

Figure 3.1 Research Methodology Layout diagram

3.1 Site selection

The road section considered for this study is Dessie to Kombolcha road with stretch of 20.9km. The sampling method used is clustering based on total number of drainage structures (Culverts and Bridge) and horizontal curve. Accordingly, a total of 25 Bridge/culvert crossings has been considered on this research work. Since the main objective of the study is to prevail effect of drainage structures on the road consistency specifically and to set means to measure road consistency as general, out of roads which have large number of bridges, culverts and horizontal curves per kilometer, Dessie to Kombolcha road section has selected due to its accessibility and nearness to Addis. Therefore, the result of this research will be applicable to only roads that have similar geometric, topographic and traffic characteristics with Dessie – Kombolcha road section.

According to Geometric design manual of ERA (2013), road from Kombolcha to Dessie is functionally classified as Trunk road. On this road section, there are a number of horizontal curves and drainage structure crossings. As the objective of this research was to show the existence of geometric design inconsistency on this road section and particularly due to the effect of drainage structures i.e. Bridges and Major culverts on road geometric design consistency, locations with horizontal curves and drainage structure like bridges and major culverts were considered as focus areas to collect data like operational and design speeds and crash histories that are related to locations with bridges, culverts and horizontal curves.

The prevailing annual average daily traffic (AADT) of the road section was counted to cross check capacity of the road with operating traffic volume by projecting a four hours traffic volume record to an equivalent 24hrs. traffic. This is done by multiplying the four-hour's averaged and factored hourly traffic by 24. The peak hour factor was found by dividing the maximum hourly traffic volume by the average traffic. This is to avoid any influence incorporated due to traffic volume beyond road capacity. Similarly, spots (study locations) are selected to be on the rural sections where any vehicle can be driven with free flow speed. In doing so, the effect of congestion due to traffic signals and stop signs has been eliminated on the result.

Traffic data collected during field data collection show, Kombolcha – Dessie road section has AADT of 2,220. The traffic composition of the study area comprises all types of vehicles with mini buses operating between Kombolcha and Dessie and Truck trailers and FSRs that transport different commodities from Addis to Mekele as dominant vehicle component.

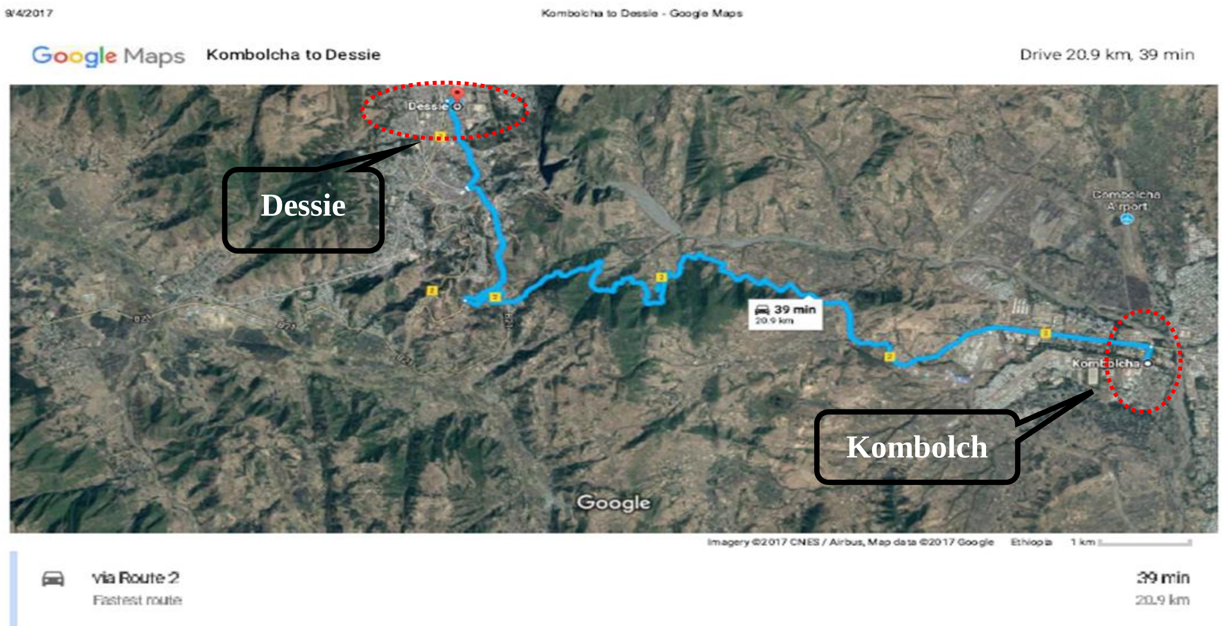

Figure 3.2 Study area map [Source: Google earth 2017]

3.2 Data Collection

3.2.1 Traffic accident data

As part of data collection secondary, Crash accident data associated with bridge/culvert crossings within 10m range on both side of bridge has been collected from traffic police office. Three years traffic accident data has been collected from Kombolcha traffic police office for the study area and also six years accident data has collected for federal roads at Addis Ababa. Primary data on crash history was collected from Questionnaire filled by drivers for the purpose of observing the influence of bridge/culvert crossings on driving speed and crash frequency on bridge/culvert crossings. Two hundred questionnaires were distributed for drivers at Kombolcha Bus station who drive on Kombolcha to Dessie road section. Out of 200 drivers only 103 drivers have responded on the questionnaire correctly by answering all the questions.

One of parameter used to measure effect of drainage structures on the geometric design consistency of a given road section is traffic accident rate. Traffic accident is a consequence of repeated change of speed on a road section. As obstructions and defective alignments that cause repeated change of driving speed increases on a road alignment, the probability to face crash accident also increases.

To see effect of bridge/culvert crossings on traffic accident rate, a six years traffic accident statistic has been collected for federal roads at Addis Ababa whereas due to absence of recorded data, only three year's crash data has been taken on Kombolcha – Dessie road section at Kombolcha Traffic Police office. Traffic accidents data has categorized based on the location it happened and severity of the accident. To measure vulnerability of bridge and culvert crossings for traffic accidents, percentage of crash types out of the total traffic accidents happened on bridge/culvert crossings and off drainage structures has been accessed separately. Raw data for traffic accident record is given on the appendix-C at the back of the paper.

Table 3.1 Traffic accident data summery table for Federal roads from 2002-2007

Six years accident statistics data summery table for Federal Roads					
Location	Fatality	Severe injury	Minor injury	property Damage only	Total
Bridge & Culvert	90	70	103	543	***806***
Other than Bridge & Culvert	2,108	7,134	5,689	65,362	***80,293***
Total	***2,198***	***7,204***	***5,792***	***65,905***	***81,099***

Table 3.2 Traffic accident data summery table for Kombocha – Dessie road from 2005-2008

Three years traffic accident statistics data summery table for Kombolcha to Dessie road section					
Location	Fatal	Severe injury	Minor injury	property Damage	Total
Bridge & Culvert	3	2	-	8	***13***
Other than Bridge & Culvert	36	40	81	98	***255***
Total	***39***	***42***	***81***	***106***	***268***

On the questionnaire interview of drivers 200 questionnaires has been distributed on Kombolcha bus station. Questions included on the questionnaire are tended to investigate driving speed of drivers on bridge/culvert locations, crashing accident history of drivers, number of crashing accident faced by drivers on bridge/culvert locations, cause of crashing accident faced on bridge/culvert locations and finally drives are asked to state their comments on currently serving bridge/culverts with regard to improve driving comfort and crashing accidents on these bridge/culvert zones. Out of 200 questionnaires distributed only 103 respondents have replied on the questions responsively. Drivers response data on the questionnaire is provided on the appendix-D at the back the paper.

3.2.2 Geometric Data

Geometric data has been collected in two ways i.e. from field observation and design review. Data like, existence of guardrails on bridges and approach roads, location of drainage structures and minimum horizontal clearance on horizontal curves had collected on the field survey whereas radius of horizontal curve, Length and width of culverts and bridges have been taken from design review. For this reason, design data for selected sites has been taken from ERA Northern district record and documentation office. Whereas during field observation width and length of bridges and culverts had taken by direct field measurement and existence and absence of guardrails on bridges and approach roads has been collected with the aid of location photos.

Photo 2: Bridge location with Broken Guard rails

Photo 1: Bridge approaching road with insufficient horizontal clearance for sight distance

Table 3.3 Design data for bridges and culverts at Kombolcha to Dessie road project

Design data for **Bridge Length**					
No.	**Type**	**Length(m)**	**No.**	**Type**	**Length(m)**
1	T-Guarder Bridge	16	**14**	Slab Bridge	6
2	Slab Bridge	10	**15**	Slab Bridge	6
3	Slab Bridge	8	**16**	Slab Bridge	8
4	Slab Bridge	6	**17**	Slab Bridge	8
5	T-Guarder Bridge	15.5	**18**	Slab Bridge	8
6	Slab Bridge	8	**19**	T-Guarder Bridge	16.5
7	Slab Bridge	8	**20**	Slab Bridge	8
8	Slab Bridge	6	**21**	Slab Bridge	8
9	Slab Bridge	6	**22**	T-Guarder Bridge	15
10	Slab Bridge	8	**23**	Slab Bridge	6
11	Slab Bridge	6	**24**	T-Guarder Bridge	16
12	T-Guarder Bridge	16	**25**	Slab Bridge	8
13	Slab Bridge	8	**26**		

3.2.3 Speed Data

The actual operating speed data has been measured for selected 5 horizontal curves and 10 bridges and culvert structures by considering vehicles passing a 10m segment over 15 minutes time period. Since the aim of the study is to measure road consistency not the average operating speed of the whole vehicle, only mini buses, Dump trucks, Isuzu, Larger Buses and track trailers are considered on measuring operating speed on horizontal curves and bridge and culvert crossings. If the aim of the research is to measure average operating speed of the road section, it will be mandatory to consider the speed of all vehicles operating on the road section. Because, the average speed observed on a given road section is a function of operating speed of all vehicles operating on a road section. But, since the objective of the research was to observe the difference in operating speed on bridge/culvert crossings with other section of the road, it is sufficient to observe operating speed of dominant vehicle types operating on the road section. For these reason, the above listed vehicle types which are dominant vehicles on Kombolcha – Dessie road section are considered for speed measurement. A total of 47 vehicles which composes 10 small vehicles, 15 mini buses, 9 small trucks, 4 large trucks, 5 large buses and 4 truck trailers has been considered per spot during measuring operating speed. Design speed data has taken from the design input data whereas posted speed limit has been collected on filed observation supported by aerial photo. The prevailing operational speed was recorded by considering 10m stretch spots on the entry and exit side of Bridges, culverts and horizontal curves. All the data collection sheet formats are presented on the appendix-B at the back of this research work.

Photo 3:Photos taken on Kombolcha to Dessie road during spot speed measurement

Operating speed is one the most common parameter used to measure performance of a given road section. So far different scholars have used 85th percentile operating speed as a means for measuring consistency of a road alignment. Professor Watters (2007) and Camacho and his colleagues (2013) have used two criterions i.e. variation between the design speed and 85th percentile operating speed of the whole alignment and variation of 85th percentile operating speed on different sections of a given road alignment. On these research work, operating speed data has been observed on different locations of road from Kombolcha to Dessie. Operating speed was observed on tangent, Horizontal curve, Bridge and culverts on tangent section and Bridges and culverts on horizontal curve locations. The observed speed values for each vehicle type on a given location changed to 85th percentile speed based on the frequency of vehicles recorded operating at a given range of speed. Percentile speed observed on bridge and culvert locations has compared with operating speed value observed on tangent and horizontal curve locations.

Spot speed measurement was carried out on different road sections to show the variation of operating speed. Tangent section, bridge/culvert locations on tangent alignment, Bridge/culvert crossings within horizontal curve locations and pure horizontal curve locations are treated separately to see their effect on operating speed. Even, bridges located on tangent section and on horizontal curve locations have been considered separately for the sake of investigating the combined effect of horizontal curves with Bridge or Culverts on operating speed. Tables below show the 85^{th} percentile operating speed at different sections of the road. Due to the uniformity of the road width throughout the length, only two spots have been considered on tangent section. A total of 94 vehicles was considered on tangent section for the determination of 85^{th} percentile speed. Raw data recorded for individual vehicle types considered is provided on the Appendix – B at the back of the paper. A table showing Observed frequency of vehicles operating at a given range of speed value and 85^{th} percentile operating speed calculation is shown on table 3.4 below.

Table 3.4 Observed frequency and percentage of vehicles operating at a given range of speed on tangent section

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<= 10	0	0.00
<= 15	0	0.00
<= 17.5	0	0.00
<= 20	0	0.00
<=22.5	0	0.00
<=25	0	0.00
<=27.5	0	0.00
<= 30	4	4.26
<=32.5	11	11.70
<=35	19	20.21
<=37.5	28	29.79
<=40	36	38.30
<=42.5	50	53.19
<=45	56	59.57
<=47.5	68	72.34
<=50	79	84.04
<=52.5	82	87.23
<=55	87	92.55
<=57.5	88	93.62
<=60	88	93.62
<=62.5	89	94.68
<=65	91	96.81
<=67.5	91	96.81
<=70	94	100.00

Horizontal curves are sensitive areas in the highway alignment especially when they are constructed with smaller radius. Horizontal curves have a tendency to minimize operating speed compared to tangent alignments. Radius of a curve is critical factor that has greater influence on the operational speed of vehicles on horizontal curves. For these research work five horizontal curves with different length of radius has been considered to observe the effect of curves on operating speed. A total of 235 vehicles have been taken to observe their operating speed and to determine 85^{th} percentile operating speed at horizontal curve. Since the objective of the research is to show the effect drainage structures i.e. bridges and culverts not horizontal curves, an average 85^{th} operating speed of vehicles on five horizontal curves is used for comparison.

Record of observed operating speed data on horizontal curves is provided on appendix-B at the back of the paper. Table 3.5 below shows calculation of 85^{th} percentile operating speed for vehicles on horizontal curves. As effect of vehicle type is a marginal concept for this research, operating speed of individual vehicle types are not considered separately rather the averaged operating speed of the whole vehicles considered on a given road section has given a focus.

Table 3.5 Observed frequency and percentage of vehicles operating at a given range of speed on horizontal curves

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<= 10	0	0.00
<= 15	8	3.40
<= 17.5	22	9.36
<= 20	38	16.17
<=22.5	50	21.28
<=25	61	25.96
<=27.5	106	45.11
<= 30	151	64.26
<=32.5	181	77.02
<=35	203	86.38
<=37.5	228	97.02
<=40	231	98.30
<=42.5	234	99.57
<=45	235	100.00
<=47.5	235	100.00
<=50	235	100.00
<=52.5	235	100.00
<=55	235	100.00
<=57.5	235	100.00
<=60	235	100.00
<=62.5	235	100.00
<=65	235	100.00
<=67.5	235	100.00
<=70	235	100.00

The third and main focus area of this research work is to determine effect of bridge and culvert locations on the operating speed value of vehicles. Bridges and culverts located on tangent and horizontal curve zones will have different level of influence on the operating speed of vehicles. For this reason, bridge and culvert crossings located on the tangent alignment and those located within horizontal curve have been threated separately. Five bridge and culvert locations on the tangent and another five crossings on the horizontal curve have been considered for measurement of 85th percentile operating speed on drainage structure crossings.

Culvert and bridge crossings observed on Kombucha to Dessie road have the same width. Therefore, there is no other factor that should be considered while measuring operating speed on bridge and culvert crossings on tangent sections. But, for bridges and culverts located on horizontal curves, radius of the horizontal curve has its own effect on the operating speed. For these reason 85th percentile operating speed has been measured separately for bridges and culverts located on horizontal curves with different length of radius.

Table 3.6 Observed frequency and percentage of vehicles operating at a given range of speed on Bridge culverts located on tangent section

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<= 10	0	0.00
<= 15	0	0.00
<=17.5	0	0.00
<=20	24	10.21
<=22.5	63	26.81
<=25	80	34.04
<=27.5	138	58.72
<=30	208	88.51
<=32.5	231	98.30
<=35	234	99.57
<37.5	235	100.00
<=40	235	100.00

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<=42.5	235	100.00
<=45	235	100.00
<=47.5	235	100.00
<=50	235	100.00
<=52.5	235	100.00
<=55	235	100.00
<=57.5	235	100.00
<=60	235	100.00
<=62.5	235	100.00
<=65	235	100.00
<=67.5	235	100.00
<=70	235	100.00

Table 3.7 Observed frequency and percentage of vehicles operating at a given range of speed on Bridge and culverts located on horizontal curves

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<= 10	0	0.00
<= 15	8	3.40
<=17.5	24	10.21
<=20	54	22.98
<=22.5	109	46.38
<=25	150	63.83
<=27.5	215	91.49
<=30	232	98.72
<32.5	233	99.15
<=35	235	100.00
<37.5	235	100.00
<=40	235	100.00

Speed (km/hr.)	Observed Frequency	% of Vehicles operating at or less than at speed range
<=42.5	235	100.00
<=45	235	100.00
<=47.5	235	100.00
<=50	235	100.00
<=52.5	235	100.00
<=55	235	100.00
<=57.5	235	100.00
<=60	235	100.00
<=62.5	235	100.00
<=65	235	100.00
<=67.5	235	100.00
<=70	235	100.00

3.3 Data Analysis Method

To prove the effect of brides and culverts on operating speed and road traffic accident, statistical data testing methods like t-test, R^2 and crash per million vehicle kilometers (CMVK) were used. Linear regression equation with two independent variables has developed by considering 85th percentile operating speed(V_{85}) as dependent variable and horizontal clearance on road side and radius of horizontal curves on bridge and culvert crossings as independent variables to predict operating speed at bridges and culverts. Multiple correlation coefficient (R) and coefficient of determination (R^2) is used to explain the strength of relationship between the dependent variable and independent variables. Regression model equation with dependent and independent variables is shown below.

$Y = b + m_1X_1 + m_2X_2$ where 'Y' is average 85th percentile operating speed at Bridge/culverts located on horizontal curve, 'b' is y-intercept value, X_1 and X_2 are radius of horizontal curve and horizontal clearance on the road side at which bridge/culvert is located respectively, m_1 & m_2 are values that indicate rate of change of as X_1& X_2 changes in one unit.

To observe effect of length of radius and horizontal clear distance on 85th percentile operating speed, 10 bridge and culvert locations at horizontal curve with different length of radius and horizontal clearance has been considered. Field observed and calculated data is shown on the table 4.3 below.

Horizontal clearance distance required between the road edge and an obstructing object for provision of sufficient sight distance is a function of speed and radius of horizontal curve. If a vehicle is located at point A as shown on the figure 3.4 below on the curve and the object is at point *B,* then the line of sight is the length of chord *AB.* The horizontal distance traversed by the vehicle when moving from point *A* to point *B* is the length of arc *AB.* The central angle for arc is defined as Δ (in degrees).

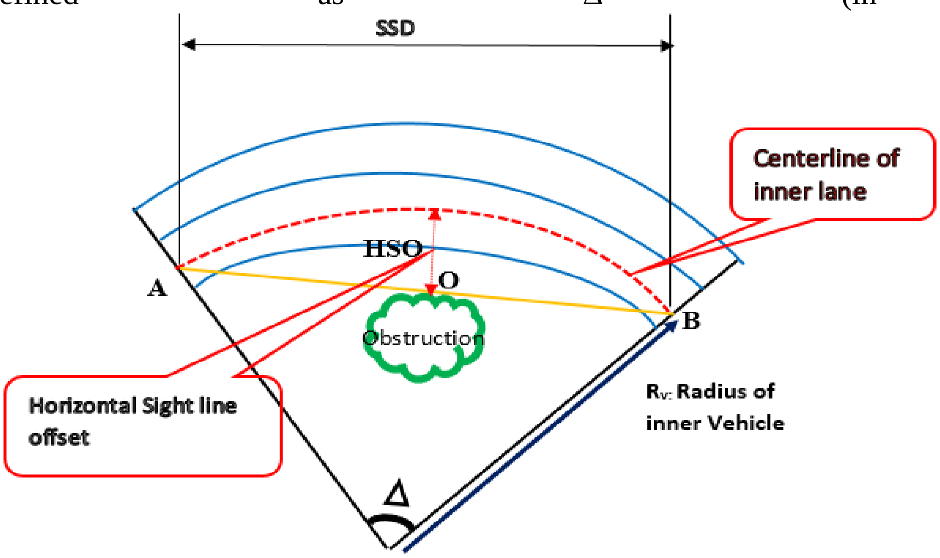

Figure 3.3 Effect of Road side obstruction on sight distance on horizontal curve locations

Thus, the expression for SSD is:

$$SSD = \frac{\pi * R_v * \Delta_s}{180} \text{ ------------------------------------ } (3.1)$$

Where, SSD is stopping sight distance, R_v is radius of inner vehicle and Δ_s is central angle of horizontal curve.

Rearranging and solving for Δ_s on equation 3.1 gives,

$$\Delta_S = \frac{SSD * 180}{\pi * R_v} \text{ ------------------------------------ } (3.2)$$

Appling cosine law for half of the central angle by considering triangle 'AOΔ' gives an equation for determination of HSO which is the clear distance between the obstructing abject and edge of the road.

$$HSO = R_v\,(1 - \cos(\frac{90 * SSD}{\pi * R_v}) \text{ ------------------------------------ } (3.3)$$

Equation 3.3 shows that there is a relationship between HSO and SSD. Rearranging the equation and expressing SSD in terms of the other parameters provide, equation for SSD in terms of Radius and HSO.

Based on equation 3.3 the required horizontal clear distance between road edge and obstructions on the side of road has been determined and it has compared with the existing (provided) horizontal clearance.

Operating speed at bridge was also accessed on in relation to horizontal curve radius and clear horizontal clearance distance. Based on the observed data, speed prediction model has been developed for bridge and culvert crossing at horizontal curve. The result of regression equation has shown on the result and discussion section.

To measure road alignment consistency in terms of operating speed variation specifically by considering variation of 85th percentile operating speed on tangent section and on bridge/culvert locations, alignment measurement technique used by professor Watters is used on this research. In this method variation of operating speed between different road section and difference between operating speed and design speed is used to measure consistency of road alignment consistency. Therefore, observed 85th percentile operating speed variation between tangent and bridge/culvert locations has been used.

Watter's criteria which uses posted speed and an average 85th percentile speed as means to measure road consistency is not the concern of this research work. This because the main objective this research work is to show the effect of bridge/culvert crossing sections on the consistency of a given road section. Therefore, variation of operating speed between tangent section and bridge/culvert crossings has been taken into consideration for alignment consistency measurement at bridge/culvert crossings.

Left tailed t-test method is also used to test the significance of effect of bridges and culverts on operating speed. For these reason, 85th percentile operating speed at tangent section and Bridge and culvert crossings is observed separately for the sake of measuring effect of drainage structures on operating speed. Frequency distribution graph of all the observed speed value resembles graph of standard normal distribution curve. Figure 4.6 shows that frequency distribution of speed is higher near to the mean value of operating speed both on the right and left side which gives bell shaped frequency distribution curve which resembles frequency distribution graph of normally distributed variable. This the reason why t-test method is selected as method of hypothesis testing.

The other parameter used for the measurement of effect of drainage structures is crash accident rate associated with bridges and culverts. Bridge and culvert accidents have been analyzed in terms of number and severity of accidents. Number of accidents per million vehicle kilometers on bridge and culvert is compared with those accidents happened away from bridges and culverts. Therefore, road traffic accident statistics for the last six and three years have been observed on the federal roads and on Kombolcha to Dessie road section respectively. Percentage of fatal, severe injury, minor injury and property damage accidents out of total accidents happened on bridge and culvert crossings and as well as those happened off bridge and culvert has been calculated to compare crash frequency and severity across bridge and non-bridge locations.

Chapter Four: Result and Discussion

4.1 Operating speed

4.1.1Tangent section

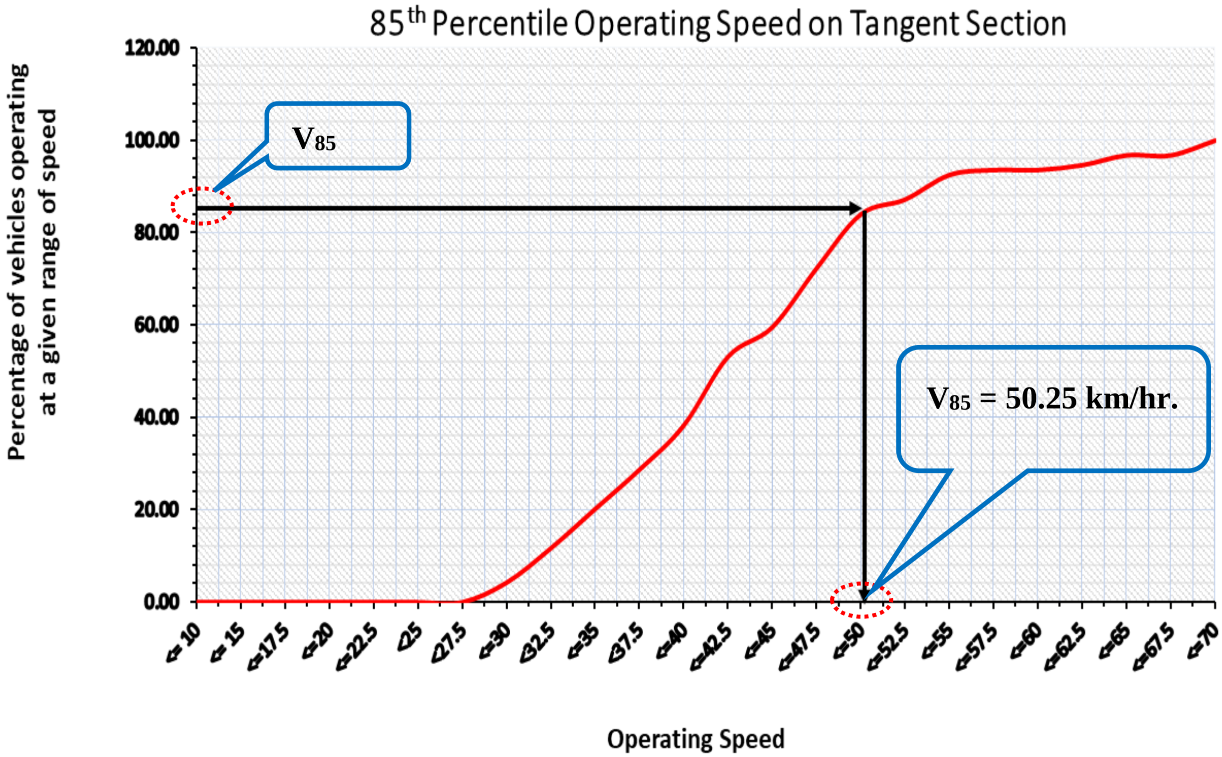

Figure 4.1 85th percentile operating speed of vehicles on tangent section

As it can be seen on the table 3.4 above, 100% of the vehicles considered were operating at speed greater than 27.5km/hr. Whereas majority (45.74%) of the vehicles were driven between a speed range of 40km.hr. and 50km/hr. As it has been highlighted on the table 3.4, the 85th percentile operating speed on tangent section is between 50km/hr. and 52.5km/hr. Figure 4.1 above shows that the 85th percentile operating speed of the vehicles is 50.25km/hr. i.e. 85% of the vehicles operating on the tangent have speed of <=50.25km/hr.

4.1.2 Horizontal Curve

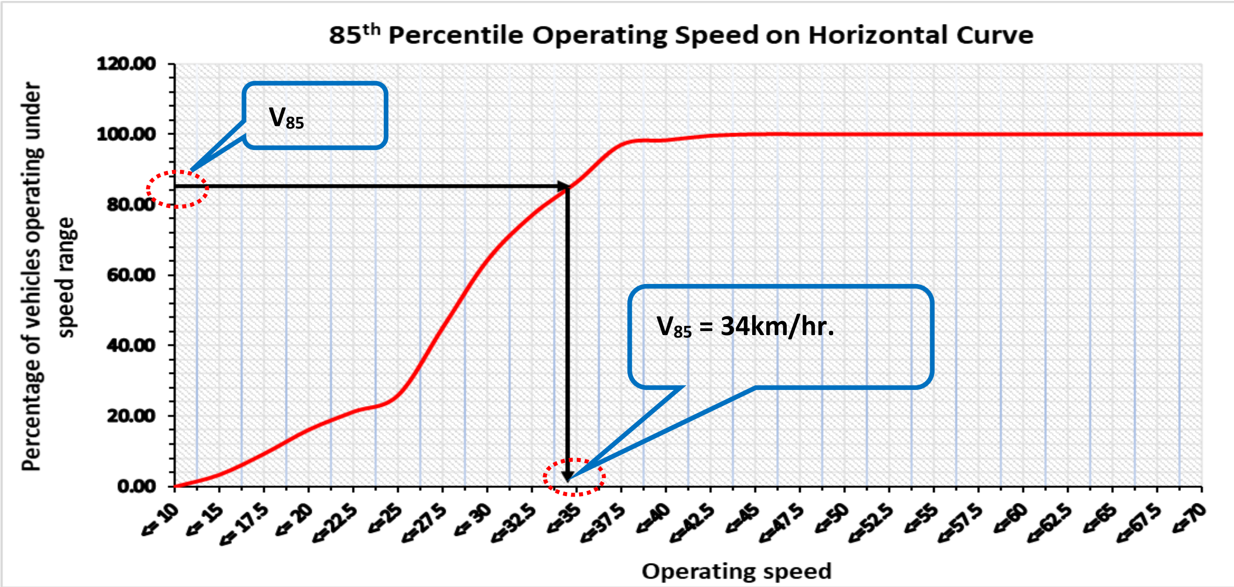

Figure 4.2 85th percentile operating speed of vehicles on horizontal curve

Table 3.5 above show that 100% of the vehicles considered on horizontal curve were operating at a speed less than 45km/hr. Whereas majority of vehicles (51.06%) were driven between a speed of 25km/hr. and 32.5km/hr. Table 3.5 also shows that 85th percentile speed for horizontal curves have been reduced to be between 32.5km/hr. and 35km/hr.

Figure 4.2 above shows that the 85th percentile speed of vehicles on horizontal curve is 34km/hr. It means that 85% of the vehicles observed on the horizontal curve had operating speed which less or equal to 34km/hr. Compared to operating speed observed on tangent section, there is speed reduction of 16.25km/hr. on horizontal curves. Not only reduction in 85th percentile operating speed but also about 45% of the observed vehicles were driven at speed less than 27.5km/hr. and there is no vehicle on horizontal curve operating at speed greater than 45km/hr.

4.1.3 Bridges and culverts

The figures 4.3 and 4.4 below show that operating speeds on bridge and culvert locations are highly affected by bridges and culverts. It is also seen that bridge crossings located on horizontal curves have greater influence than those bridge crossings on tangent section. Even, length of radius for horizontal curve on which the bridge and culvert is located has an influence on operating speed of vehicles. Bridge and culverts on tangent section have an average 85th percentile operating speed of 29.75km/hr. whereas those bridges located on horizontal curve have 26.75km/hr. But, this 26.75km/hr. operating speed is a function of length of radius of horizontal curve on which bridge and culvert is located.

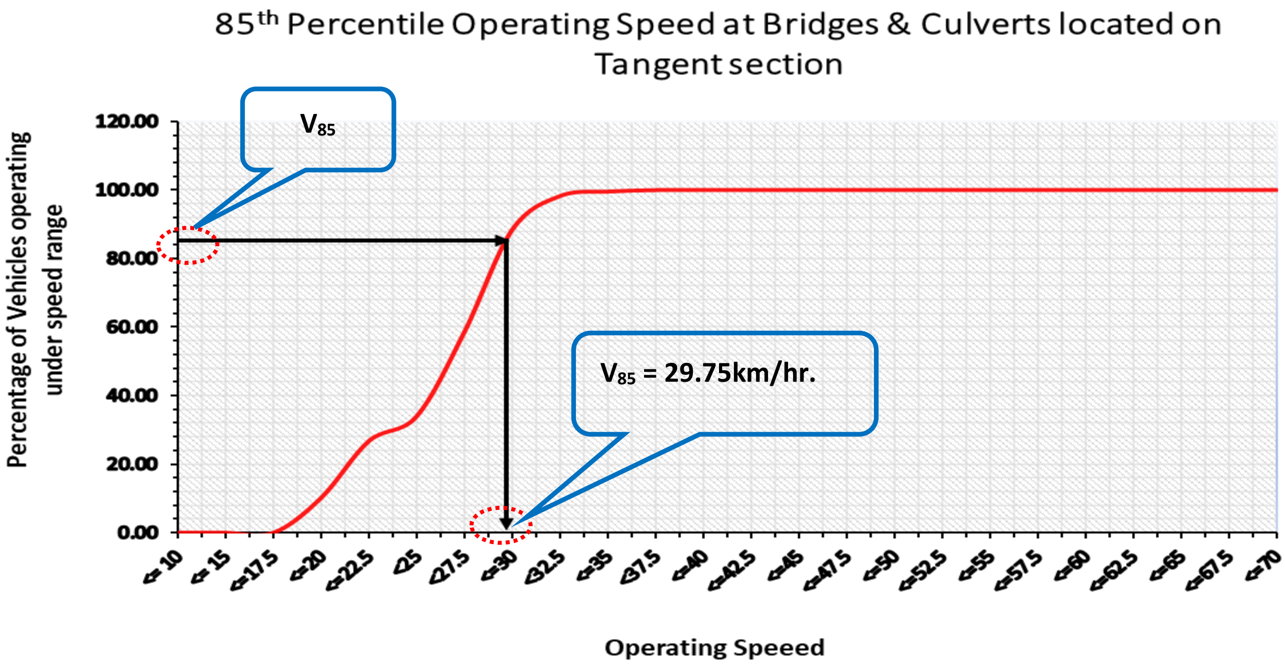

Figure 4.3 85th percentile operating speed on Bridges and culverts at tangent alignment

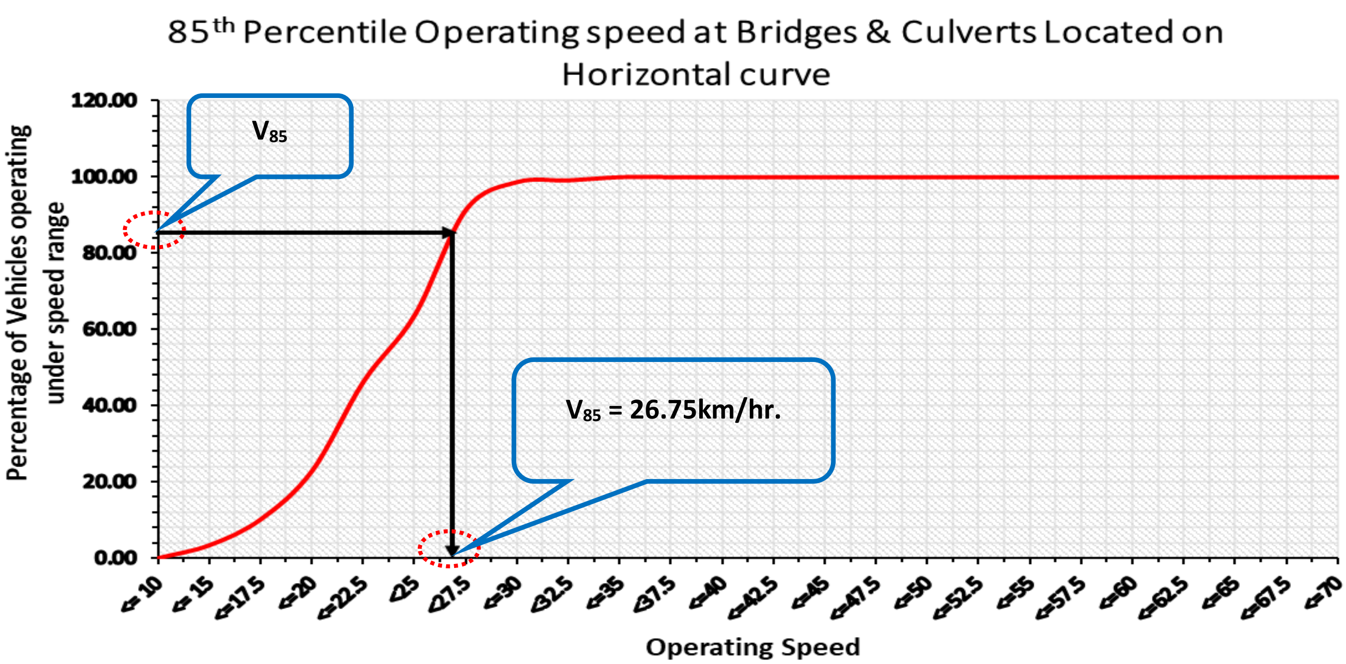

Figure 4.4 85th percentile operating speed on Bridge &Culvert on horizontal curve

Table 4.1 Average 85th percentile operating speed on different road section

85th percentile operating speed		
Tangent section	**Bridge/Culvert on tangent**	**Bridge/Culverts on H. Curve**
50km/hr.	29.75km/hr.	26.75km/hr.

As it the table above shows, there is greater variation between 85th percentile operating speed on tangent and bridge and culvert crossings. Measurement of road alignment consistency by considering variation of operating speed indicates that bridge and culvert crossings are not consistent with the tangent road section. For both cases, i.e. bridge and culverts at tangent and for those located at horizontal curve locations change of speed is greater than 20km/hr. as shown below.

$\Delta V_{85(\text{tangent, bridge at tangent})} = |V_{85(\text{tangent})} - V_{85(\text{bridge at tangent})}| = 50\text{km/hr.} - 29.75\text{km/hr.} = \boldsymbol{20.25\text{km/hr.}}$
$\Delta V_{85(\text{tangent, bridge at horizontal curve})} = |V_{85(\text{tangent})} - V_{85(\text{bridge at horizontal curve})}| = 50\text{km/hr.} - 26.75\text{km/hr.}$ $\boldsymbol{=23.25\text{km/hr.}}$

Change of 85th percentile speed for both cases shows that remark type "C" should be recommended for alignments on the bridge and culvert locations i.e. redesigning road alignments on bridge and culvert locations is recommended. Therefore, widening of bridge/culvert lanes, provision of separated pedestrian and animal crossings, installation of strong and tall enough bridge/culvert side barriers are some of issues that should be taken into consideration while redesigning an alignment.

4.1.4 One tailed t-test

Left tailed t-test hypothesis testing method has been used to test the significance of the influence of bridge and culvert crossings on the 85th percentile operating speed vehicles. For this purpose, observed 85th percentile operating speed on bridge and culvert has compared with an average 85th percentile operating speed observed on tangent section.

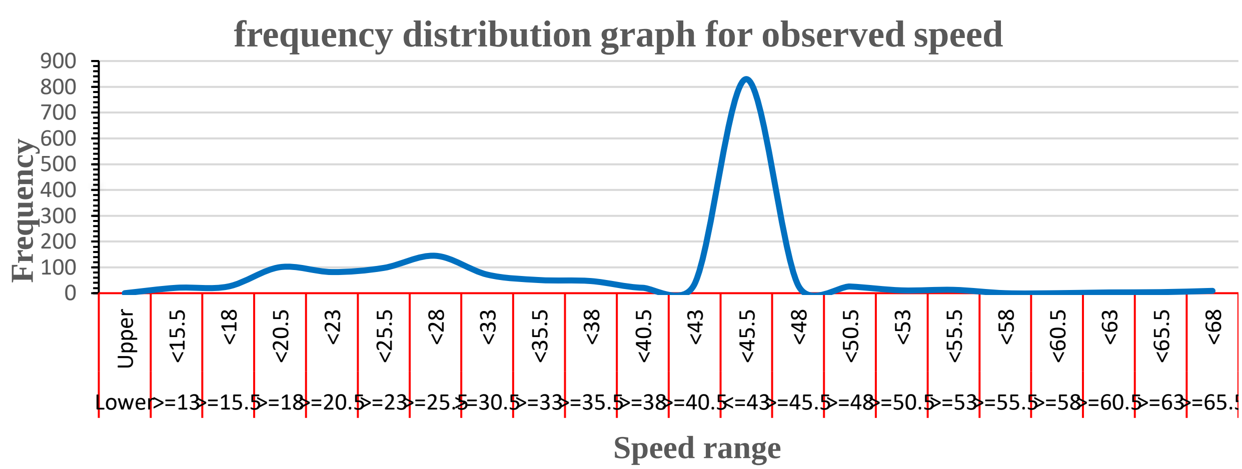

Figure 4.5 Frequency distribution graph for speed of observed vehicles

Figure 4.5 above shows that plot of frequency of observed speed on field looks like a bell with a maximum frequency value near to the mean operating speed. Since there is no data about the population standard deviation and the frequency distribution graph of the sample speed data resembles the bell shaped normal distribution graph, t-test was selected to measure the significant effect of bridges and culverts on operating speed.

Ten (10) different bridge and culvert locations with different geometric features have been taken into consideration for the determination of average 85th percentile operating speed on these bridge and culvert locations. It has shown on the above discussion, 85th percentile operating speed on tangent section is 50km/hr. Observed 85th percentile operating speed on different bridge and culvert locations is given on table 4.2 below.

Table 4.2 85th percentile operating speed on bridge and culvert crossing

Spot-1 tangent	Spot-2 tangent	Spot-3 tangent	Spot-4 tangent	Spot-5 tangent	Spot-6 H.curve	Spot-7 H. curve	Spot-8 H. curve	Spot-9 H. curve	Spot-10 H.curve
29.5	29.5	29.25	30	29.75	29	29	26.875	25.25	22

The average 85th operational speed of bridge and culvert crossings for the data set above is 28.0km/hr. Considering confidence level of 95% and taking average 85th percentile speed on tangent section (50km/hr.) as population mean and 28km/hr. as sample mean, left tailed t-test has been conducted to see whether there is significant variation of operational speed on bridge and culvert crossings from mean speed observed on tangent section.

Null hypothesis(H_o): There is no 85th percentile operating speed variation between bridge/culvert crossings and tangent sections i.e. ($V_{85(\text{Bridge \&culvert})} = \mu = 50$km/hr.)

Where μ is mean of observed operating speed at tangent section of the road and V_{85} is 85th percentile operating speed.

Alternative hypothesis (H_1): 85th percentile operating speed at bridge/culvert crossing is less than 85th percentile operating speed at tangent section i.e. ($V_{85(\text{Bridge \&culvert})} < \mu$)

For significance level of 95%, α = 0.05. Critical value of 't' for the considered scenario has been determined as below.

Degree of freedom(Df) = n-1 where n is total number of samples taken. In this case since a total of 10 samples have been considered, Df = 10-1 = 9

By using table F for t-distribution, critical value (t_c) = -2.306

The test value is determined from the equation, $t = \frac{\bar{X}-\mu}{s/\sqrt{n}}$ where $\bar{X}$ is sample (bridge/culvert crossing) mean speed, S is standard deviation of the mean, μ is population (tangent section) mean speed and n is total number of means considered.

$t = \frac{28-50}{2.6/\sqrt{10}} = -26.76$

the test value for t is less than the critical value specified on the table. This implies that the test value is located within the critical region therefore, null hypothesis should be rejected and the alternative hypothesis should be accepted. Which means we are 95% confident to say that average 85^{th} percentile operating speed on bridge and culvert crossings are less than V_{85} on tangent section.

4.1.5 Speed prediction model at bridge/culvert crossing

For the development of 85^{th} percentile operational speed prediction model at bridge/culvert located at horizontal curve, an observed speed of ten bridge/culvert crossings located on horizontal curve with varied length of radius have been considered. Since all the bridge and culverts crossings have the same width and geometry, only effect of radius of horizontal curve has been measured. The other parameter taken into consideration with radius of horizontal curve was clear horizontal distance available between road edge and obstruction.

Table 4.3 Shows variation of 85th percentile operating speed at bridges located on horizontal curves with radius of the curve and horizontal clearance of obstruction from the road side.

No	V_{85}(km/hr.) (Y)	Horizontal clearance required(m)	length of Radius(m) (X_1)	Observed horizontal clearance (m) (x2)	Y^2	X_1^2	X_2^2	X_1X_2	X_1Y	X_2Y
1	22	4.25	85	3.5	484.00	7225.00	12.25	297.50	1870.00	77.00
2	25.25	4	100	3	637.56	10000.00	9.00	300.00	2525.00	75.75
3	26.75	3.6	120	2	715.56	14400.00	4.00	240.00	3210.00	53.50
4	27.75	2.16	180	2	770.06	32400.00	4.00	360.00	4995.00	55.50
5	29	2	200	1.5	841.00	40000.00	2.25	300.00	5800.00	43.50
6	28	3	150	2.15	784.00	22500.00	4.62	322.50	4200.00	60.20
7	25	4.25	85	3	625.00	7225.00	9.00	255.00	2125.00	75.00
8	28	1.5	300	3	784.00	90000.00	9.00	900.00	8400.00	84.00
9	24	3.125	125	2	576.00	15625.00	4.00	250.00	3000.00	48.00
10	22	4	100	3.5	484.00	10000.00	12.25	350.00	2200.00	77.00
Sum	**257.75**		**1445**	**25.65**	**6701.19**	***249375.00***	***70.37***	***3575.00***	***38325.00***	***649.45***
Mean	**25.775**		**144.5**	**2.565**						

Using equation for regression with two independent variables and one dependent variable, terms of the multiple regression equation has been determined as shown below.

$$m_1 = \frac{(\sum X_2^2)*(\sum X_1Y)-(\sum X_1X_2)*(\sum X_2Y)}{(\sum X_1^2)*(\sum X_2^2)-(\sum X_1X_2)^2} = 0.08$$

$$m_2 = \frac{(\sum X_1^2)*(\sum X_2Y)-(\sum X_1X_2)*(\sum X_1Y)}{(\sum X_1^2)*(\sum X_2^2)-(\sum X_1X_2)^2} = 5.23$$

$$b = \bar{Y} - m_1\bar{X}_1 - b_2\bar{X}_2 = 0.99$$

The multiple regression equation is: $\boldsymbol{Y_{(x1,\,x2)} = 0.99 + 0.08X_1 + 5.23X_2}$

Where X_1 and X_2 are radius of horizontal curve and clear horizontal clearance between road edge and obstruction in meter respectively and Y is operating speed at bridge/culvert crossings in km/hr.

The purpose of multiple regression model is to show how much operating speed at bridge/culvert crossing located at horizontal curve is affected by radius of the curve and horizontal clear distance between road edge and obstruction on the side of the road.

Multiple correlation coefficient (R) determination shows that there is strong correlation between operating speed at bridge located on horizontal curve and the independent variables stated above.

$$R_{(YX1)} = \frac{n\sum X_1Y - (\sum X_1) * (\sum Y)}{\sqrt{n\sum X_1^2 - (\sum X_1)^2} * \sqrt{n\sum Y^2 - (\sum Y)^2}} = 0.71$$

$$R_{(YX2)} = \frac{n\sum X_2Y - (\sum X_2) * (\sum Y)}{\sqrt{n\sum X_2^2 - (\sum X_2)^2} * \sqrt{n\sum Y^2 - (\sum Y)^2}} = 0.72$$

$$R_{(X1X2)} = \frac{n\sum X_2X_1 - (\sum X_2) * (\sum X_1)}{\sqrt{n\sum X_2^2 - (\sum X_2)^2} * \sqrt{n\sum Y^2 - (\sum Y)^2}} = -0.30$$

Where,

$R_{(YX1)}$ is correlation coefficient between operating speed and length of radius.

$R_{(YX2)}$ is correlation coefficient between operating speed and horizontal clear distance between road edge and road side obstruction.

$R_{(X1X2)}$ is correlation between the two independent variables

The above result tells that there exists a strong positive correlation between operating speed and length of radius as well as with clear horizontal distance between road edge and obstruction. Whereas the third value of correlation coefficient shows that there exists weak and negative correlation between the two independent variables. Based on the above individual R values the multiple correlation coefficient has determined as below.

$R = \sqrt{\frac{R^2_{YX1} + R^2_{YX2} - 2 * R_{YX1} * R_{YX2} * R_{X1X2}}{1 - R^2_{X1X2}}} = 0.93$ the value of multiple correlation coefficient shows that there is 93% relation between the value of operating speed at bridges located on horizontal curve with radius length and horizontal clear distance b/n road edge and obstruction at approaching road to bridge and culvert crossings.

The value for coefficient of determination (R^2) = R*R = 0.86

Coefficient of determination of 0.86 implies that 86% the value of operating speed at bridges located on horizontal curve is explained by the value of clear horizontal distance road edge and obstruction and length of radius at curve. Which means only 14% of the value of operating speed at bridge and culvert crossings at horizontal curve is affected by another variable or factor which is not considered in this model.

4.2 Questionnaire Responses

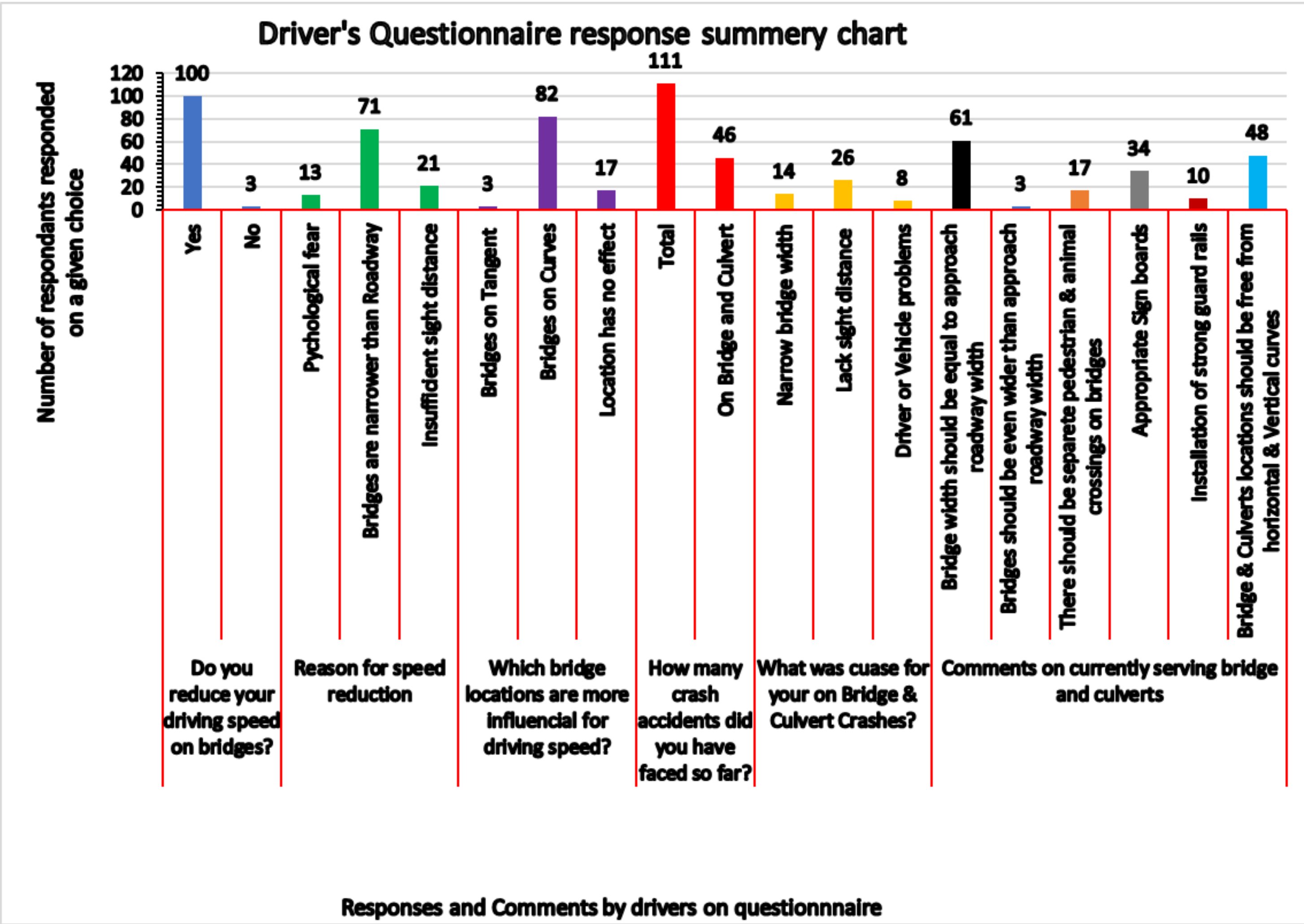

Figure 4.6 Summary of driver's Reponses on the questionnaire

Almost 99% of drives have responded that as they reduce their driving speeds on bridge/culvert locations. only 3 out 103 respondents have said as they never reduce their driving speeds on these structures. Out of respondents who have responded as bridge/culvert locations have influence on driving speed, 71 responds have stated less bridge lane width as a reason for their speed reduction, 21 drivers have stated insufficient sight distance (construction of bridge/culverts on vertical and horizontal curve locations) as their reason for speed reduction, whereas 13 respondents have explained psychological fear at bridge/culvert locations as an influencing factor for driving speed reduction.

The other issue regarding to influence of bridge/culvert on driving speed is location of these structures on the road alignment i.e. weather it is located on the tangent section or on horizontal or vertical curve. Regarding to this, 82 respondents have replied that bridge/culverts located on the horizontal curves have higher influence on the driving speed than bridges/culverts on tangent section, 17 drivers have said location has no difference what matters is existence of bridge/culvert location and the rest only 3 respondents have replied as bridges/culverts on tangent section have greater influence than other locations.

Regarding to crashing history of drivers, 111 total crashing histories was observed on 103 respondents. Since the main objective of the research is to display contribution of drainage structures on the total traffic accident and proportion of crash types on bridge/culvert locations has been well discussed above, here classification of crashing accidents by type has given marginal weight. Out of 111 total accidents faced by drivers 46 respondents have replied as they face crashing accident on bridge/culvert locations. This implies that about 41.4 % of crashing accidents faced by respondents have been on bridge/culvert locations. This figure is extremely higher than what was observed on federal roads and Kombolcha – Dessie road section. Generally, it tells us that how match bridge/culvert locations are vulnerable for traffic accidents compared to their proportion in length on a road segment. Out of the total drivers faced crashing accidents on bridge/culvert locations, 14 respondents have stated lack of bridge lane width as a reason for their collision, 26 drivers have replied lack of sufficient sight distance as cause for their collision and the rest 8 respondents have replied as vehicle or driver related problems as a cause for collision.

Lastly, respondents have stated their comments on bridges/culverts currently being serving. Accordingly lack bridge lane width, existence of bridge/culvert crossings on deep point of vertical curve or on horizontal curve with sharp radius without sufficient horizontal sight clearance and problems with installation of sign posts were highly commented issues with 61, 48, 34 respondents respectively. The other point raised by respondents as a comment is that bridge/culvert approaching guard rails are not strong enough to protect collided vehicle from falling off to river valley and even guard rails should be solid tall enough structures that impede drivers side sight into deep river valley that induces psychological fear on drivers not to drive on their extreme right side. This is because in most case on bridge/culvert collisions are face due to the tendency of drivers to drive towards the center of bridge/culvert structures. Most respondents have advised to construct lane separation structures between opposite direction lanes to avoid collision with vehicles operating in opposite direction. Generally, major comments stated by drivers on the questionnaire includes;

- Separation of opposite direction lanes with barriers on bridge/culvert location
- Construction of bridge/culverts with lane width equal to the approaching road width
- Provision of separate animal and pedestrian crossing lanes on bridge/culvert crossings
- Construction of bridges/culverts away from horizontal curves and lowest point of vertical curve

4.3 Crash rate

Figure 4.7 and 4.8 below show traffic accident and percentage of accident types by severity for off bridge and on bridge traffic accidents.

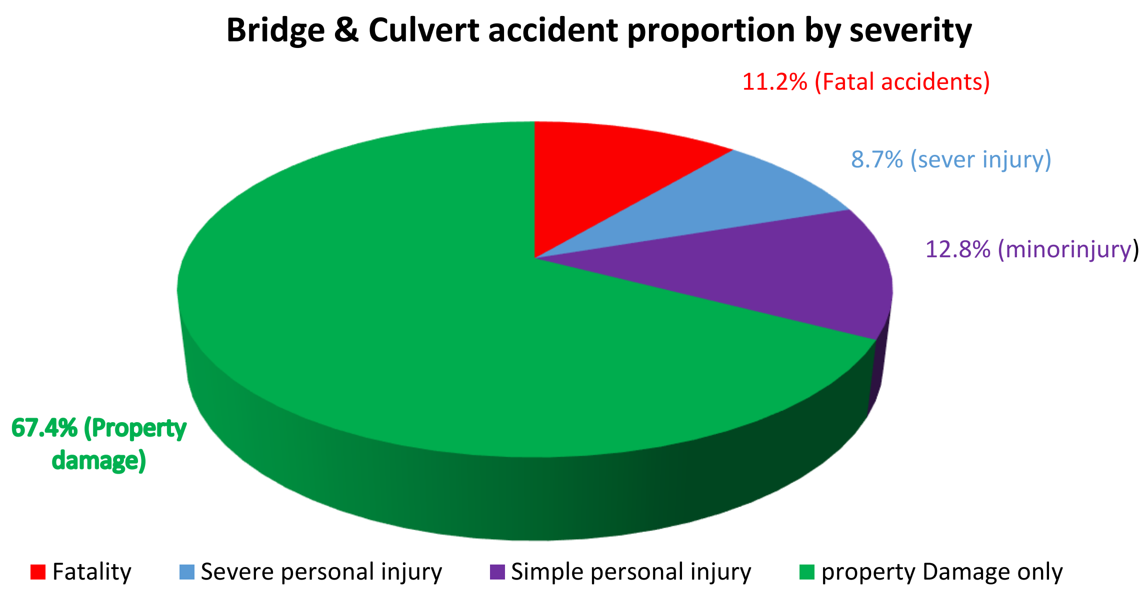

Figure 4.7 Bridge and culvert accident proportion by severity for considered federal roads

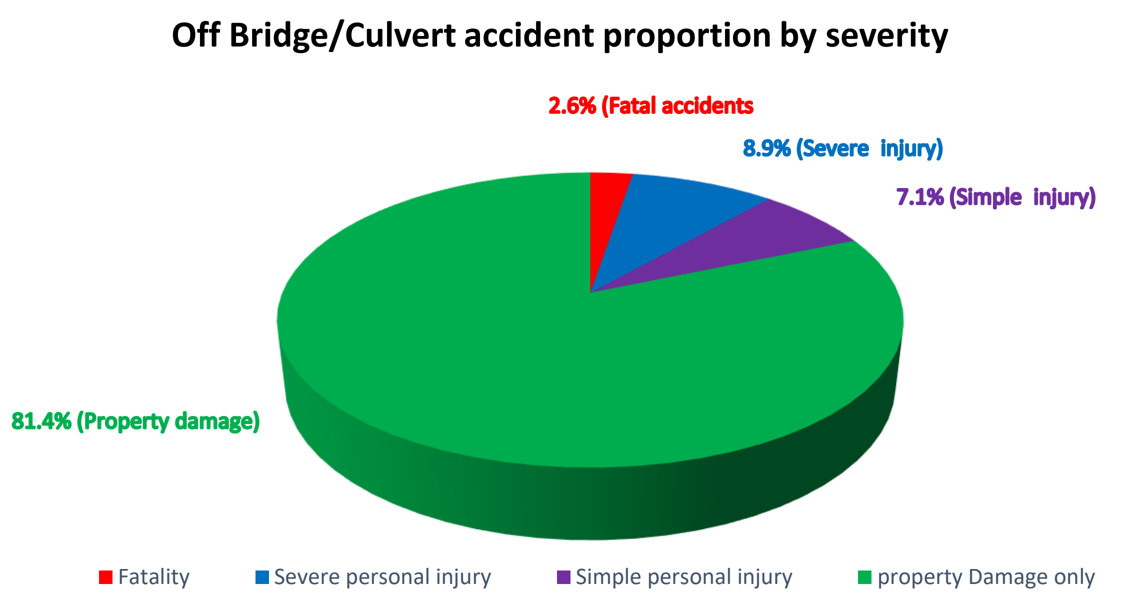

Figure 4.8 Off bridge/culvert accident proportion by severity for considered federal roads

Pie chart diagrams above show that bridge and culvert crossings are highly vulnerable for fatal accidents compared to off bridge and culvert road sections. Pie chart diagram shows that bridge and culvert locations have fatal accident percentage of 11.2% whereas off bridge/culvert locations have fatal percentage of 2.6% which implies that out of 100 traffic accidents happened on bridges/culverts, about 12 accidents will go to fatality accidents and similarly, out of 100 accidents faced on off bridge/culvert locations, only about 3 accidents will be fatal.

The above result tells us that, bridge and culvert crossings are 4 times vulnerable for fatal accidents than non-bridge/culvert sections of roads. For the rest of accident types more or less bridge/culvert locations have the same vulnerability with non-bridge/culvert locations.

Similar procedure was applied on traffic accident records taken for Kombolcha to Dessie road. Analysis result of the three years traffic accident on Kombolcha to Dessie road is shown on the chart diagram below. The same trend has observed on Kombolcha to Dessie road as it was seen on the federal roads.

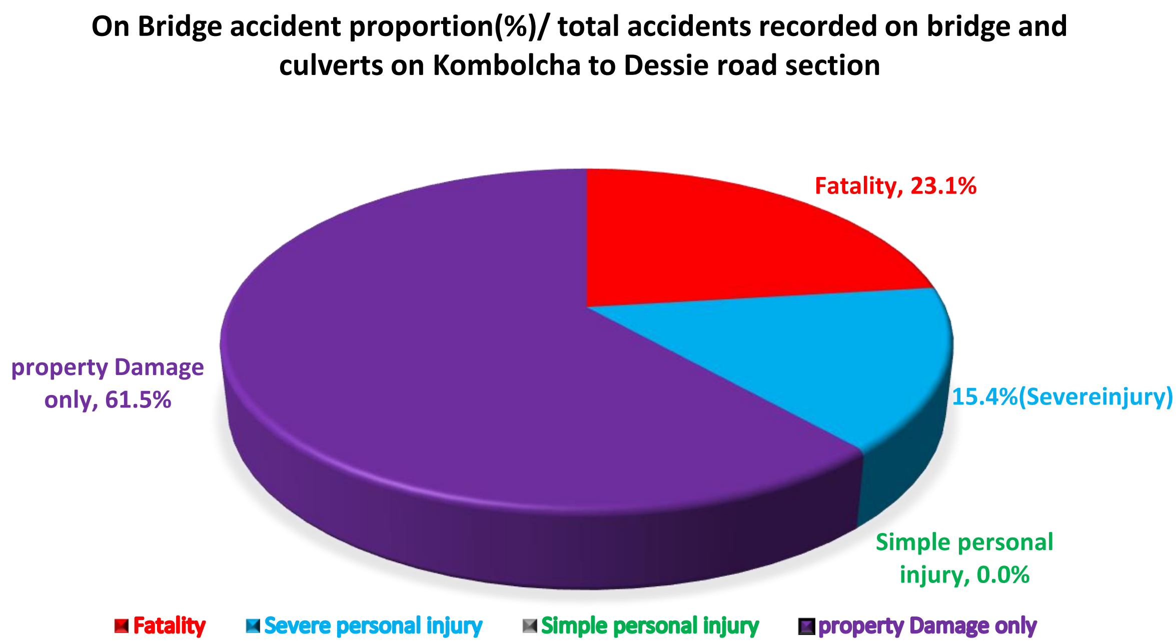

Figure 4.9 On bridge/culvert accident proportion by accident severity type for Kombolcha – Dessie road

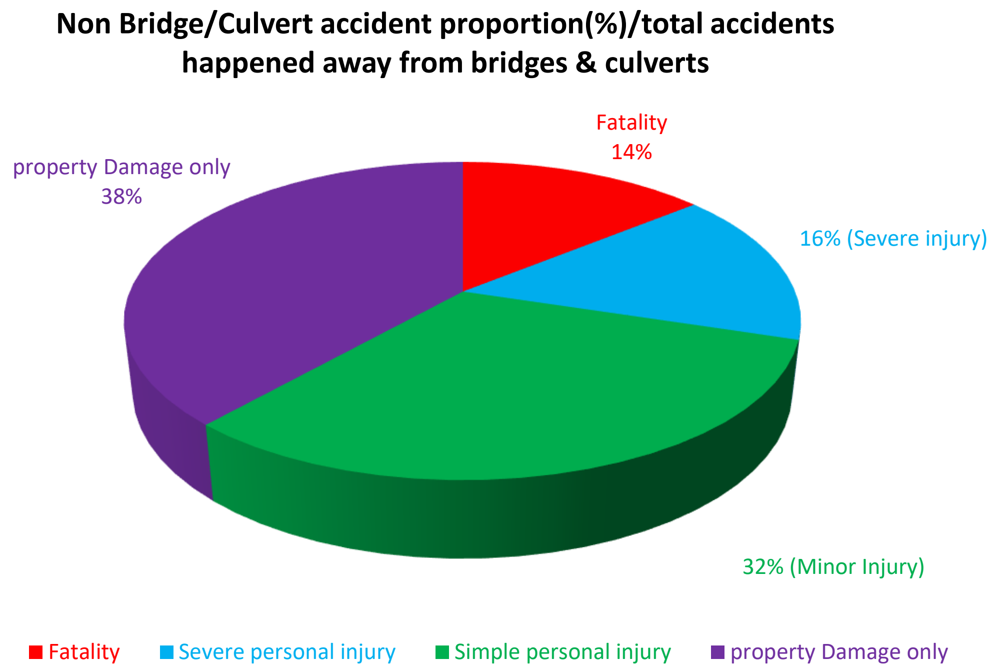

Figure 4.10 Non-Bridge/Culvert accident proportion by accident severity type for Kombolcha – Dessie road

Interpretation of pie charts above tells that Bridges/Culverts on Kombolcha to Dessie road section has 23.1% of fatal accident out of the total accidents happened on bridge and culverts whereas non-bridge/culvert sections have 14% probability for fatal accident out of the total accidents on non-bridge alignment. This implies that probability of having fatal accidents on bridges/culverts is almost twice that of non-bridge alignments.

Compared to federal roads Kombolcha to Dessie road section have higher bridge and culvert related accidents especially fatal and sever injury accident types. Fatal accidents are the most series types of traffic accident on road. As we have noted on the above discussion, bridge/culvert crossings are highly vulnerable areas for traffic accidents especially fatal accidents. The other method commonly used for traffic accident description is number of accidents per vehicle miles or vehicle kilometers. On the above discussion, it is well stated that bridges/culvert crossings are vulnerable areas than non-bridge areas. This tell us nothing about proportion of total accidents that has been recorded on bridge/culvert locations and off bridge/culvert locations. Therefore, there should be another way to state proportion of accidents that is related to bridge and culverts out of the total accidents recorded on a given road segment.

Tables and bar charts below shows proportion of accidents recorded on bridge /culvert locations for Federal and Kombolcha – Dessie roads for the last 6 and 3 years respectively. Both for federal and Kombolcha to Dessie road segments, traffic accidents have displayed location and accident type.

Table 4.4 Summary of 6 years traffic accident record for Federal roads by severity and location

Summary of 6 years traffic accident record for Federal roads by severity and location							
Fatal accidents		***Severe personal injury***		***Simple personal injury***		***Property damage***	
On Bridge	Non-Bridge	On Bridge	Non-Bridge	On Bridge	Non-Bridge	On Bridge	Non-Bridge
4.1%	95.91%	1%	99%	1.80%	98.20%	1%	99%

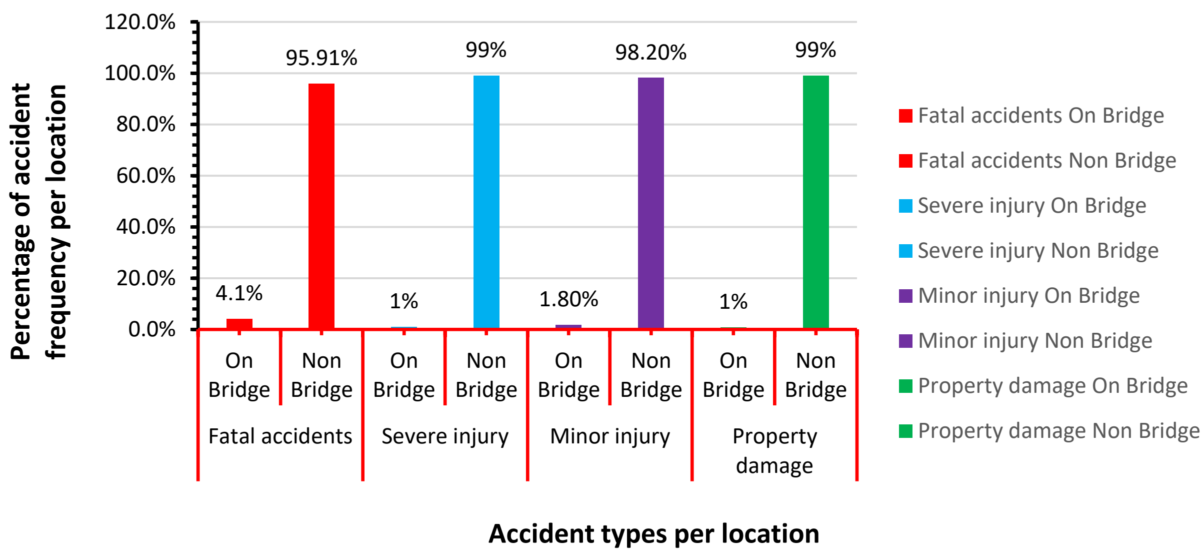

Figure 4.11 Percentage of Federal road accident by types and locations where it happened

Assessment of six years Federal roads' accidents indicate that out of total fatal accidents recorded 4.1% has been recorded on Bridges/culverts whereas 95.91% of total fatal accidents has been recorded on non-bridge/culvert locations. Similarly, for severe personal injury, simple personal injury and property damage as it shown on the bar chart, 1% up to 1.8% of accidents have been recorded on bridge/culvert crossings. It seems that proportion of accidents in percent faced on bridge/culvert crossings very low compared to that of non-bridge/culvert locations. But, if we consider proportion of length of bridges to length of total road segment on a given road section, length of bridges/culverts is insignificant. To see the practical effect of bridges/culverts on traffic accident rate, bridge length should be changed into proportional length of road segment i.e. accidents recorded both on bridge/culvert and non-bridge/culvert should be stated in terms of crashes per million vehicle miles(CMVM) or crashes per million vehicle kilometers(CMVK). For the calculation of CMVM or CMVK, three years traffic crash data on bridge/culvert zones and off bridge/culvert sections for Kombolcha – Dessie road has been considered as shown below.

Table 4.5 Summery of 3 years traffic accident record for Kombolcha - Dessie road by severity and location

Summary of 3 years traffic accident record for Kombolcha - Dessie road by severity and location							
Fatal accidents		***Severe personal injury***		***Simple personal injury***		***Property damage***	
On Bridge	Non-Bridge	On Bridge	Non-Bridge	On Bridge	Non-Bridge	On Bridge	Non-Bridge
7.7%	92.3%	4.8%	95.2%	0.0%	100.0%	7.5%	92.5%

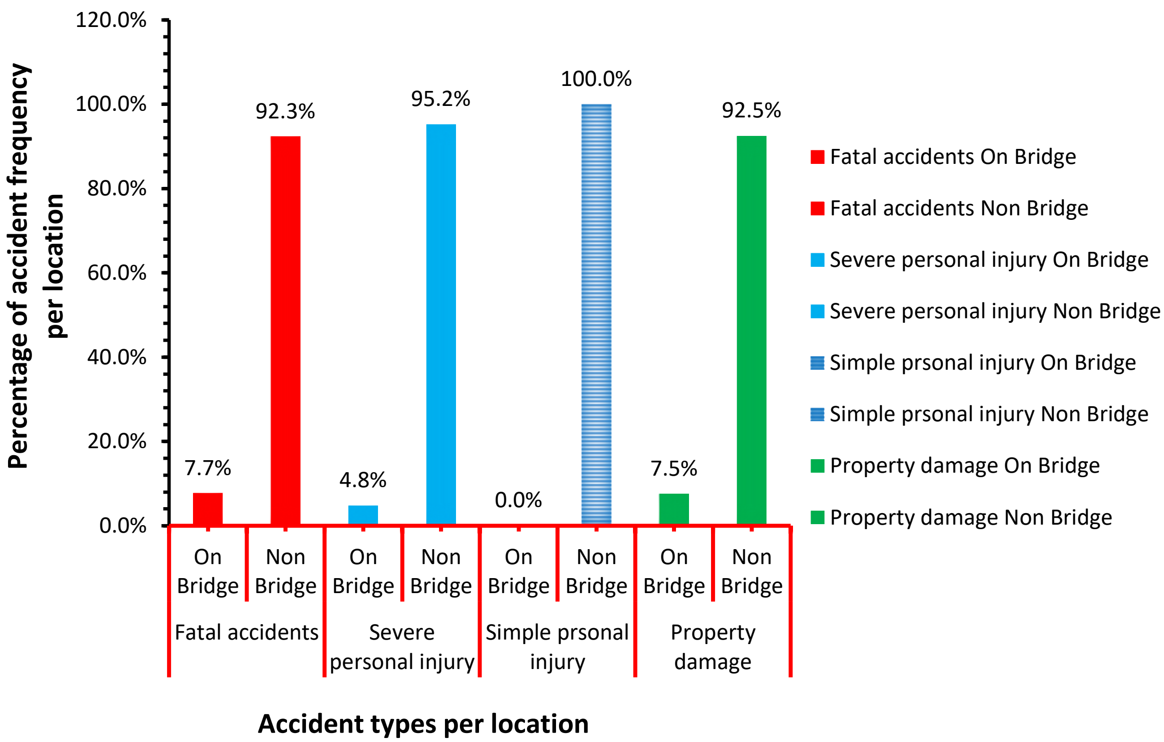

Figure 4. 12 Percentage of Kombolcha – Dessie road accident by types and locations where it happened

As it was observed on the traffic accident analysis of federal roads above, on Kombolcha to Dessie road section 7.7% of total fatalities happened on the road was related with bridge/culvert crossings whereas the rest 92.3% of fatalities has been happened on off bridge/culvert locations.

Percentage of fatalities related to bridge/culvert locations (7.7%) seems too small compared to the off bridge/culvert fatalities (92.3%). Kombolcha to Dessie road section is 20.9km with a total of 25 bridge/culvert crossings and about 36 minor pipe culvert crossings. Since minor pipe culverts are not even visible on the road surface their effect is not considered on this research work. The total length of bridge/culvert crossings on this road is 235m as shown on the table 3.3 above.

Crash per million vehicle kilometers (CMVK)

Prediction from a four hours video record on site indicates that current average daily traffic (ADT) of Kombolcha to Dessie road project is 2,220 and total length of the road section is 20.9km. Based on this data an equivalent number of crashes per million vehicle kilometers has been calculated both for bridge/culvert crossings and non-bridge zones by using traffic accident records recorded on bridge/culvert crossings and non-bridge zones.

To determine number of crashes per million vehicle kilometers per year, first we have to determine total amount of vehicle kilometers covered by vehicles operating on Kombolcha – Dessie road section by multiplying ADT by total length of road and 365 days of the year.

Total vehicle kilometers per year covered on non-bridge/culvert locations
= (total road length(Km)-Length of bridge/culvert crossings(Km)) * 365*ADT

= (20.9-0.235) *365*2,220 = ***16,744,849.5 Km***.

This means that total distance covered by vehicles operating on Kombolcha – Dessie road section per year is equal to 16,744,849.5km. To change into million vehicle kilometers, the above value should be divided by one million.

Million vehicle kilometer (MVK) on non-bridge/culvert zones per year = ***16.74***

Similarly, for bridge/culvert crossings million vehicle kilometer per year can be calculated in the same way as above. Therefore, MVK for bridge/culvert crossing has been calculated as below.

Million vehicle kilometers per year on bridge/culvert crossings = 0.235*365*2,220/10^6 = ***0.19.***

The above calculation shows that 16.74 million kilometers will covered on non-bridge zones whereas only 0.19 million kilometers will be covered on bridge/culvert zones every year on Kombolcha to Dessie road section. The main point that should be kept in mind in this discussion is that how match it is very small that the distance covered by vehicles on bridge/culvert locations per year compared to that of distance covered on non-bridge road section.

Three years traffic accident data was taken on Kombolcha to Dessie road section. Therefore, for determination of crashes per million vehicle kilometers per year, annual vehicle kilometers in million has to be changed into equivalent three years vehicle kilometers in million by multiplying the above values by number of years. Therefore,

Three years' MVK on non-bridge section = 16.74*3 = ***50.22***

Three years' MVK on bridge/culvert crossing = 0.19*3 = ***0.57***

Based on the above million vehicle kilometers and traffic accidents recorded on bridge and non-bridge locations on Kombolcha to Dessie road, frequency of observing crashing accidents on non-bridge and on bridge/culvert zones has been calculated as shown below.

- Number of crashes per million vehicle kilometer (CMVK) on non-bridge location = total non-bridge accidents/MVK = 255/50.22 = ***5.0***
- Number of crashes per million vehicle kilometer (CMVK) on bridge/culvert location = total crashes recorded on bridge and culvert/MVK = 13/0.59 = ***22.0***

From the result, we can conclude that bridge and culvert locations are extremely dangerous zones as per the current design and construction trend of Ethiopia. This is because, crash rate per million vehicle kilometer tells us that bridge and culvert locations have more than 4 folds crash rate than non-bridge zones on a given road section.

Chapter Five: Conclusions and Recommendations

5.1 Conclusions

There are a number of factors that can be considered while accessing performance and safety of a given road section. But, bridge and culvert locations are the main and visible factors affecting performance and safety of roads. It is obvious that constructing or designing roads without bridges/culverts is impossible. But, design and construction of this structures can be made in a way that has no negative effect on the road performance and safety. All the discussions above indicate that bridge and culvert locations have significant effects on performance of a given road section.

One tailed t-test at confidence level of 95% for variation of 85th percentile speed b/n bridge and culvert crossings and tangent section shows that there is significant variation (reduction) of speed at bridge and culvert locations. Accident per million vehicle kilometers indicate that bridge and culvert locations are about 4 times the accident per million vehicle kilometers on non-Bridge road sections.

Review of provided horizontal clear distance b/n road edge and obstruction on ten bridge locations as per the required clear distance for sight distance provision, all bridge locations considered lack sufficient clear distance and coefficient of determination for the multiple regression equation ($R2 = 0.86$) had indicated that 86% of the value of operating speed at bridges and culverts located on horizontal curve is explained by the radius length and clear distance provided b/n obstruction and road edge.

This is an indication of existence of poor geometric consistency around bridge and culvert locations which needs design modification. left tailed t-test result also shows that mean of 85^{th} percentile operating speed on bridge/culvert crossings is significantly less than mean of 85^{th} percentile speed at tangent section with confidence level of 95%.

The other important issue observed on bridge and culvert crossings is that, these structures are highly vulnerable for traffic accidents. Not only the higher accident rates it has, but the severity of accidents happened on these structures are higher than those happened on non-bridge/culvert locations. analysis of Crash rate per million vehicle kilometer indicates that bridges and culvert locations have rate of CMVK =22 whereas non-bridge section of the has CMVK = 5. Six years traffic accident analysis for federal roads also indicate that, accidents happened on bridge/culvert crossings have 11.2% probability of having fatal accidents whereas those accidents happened on non-bridge areas have only probability of 2.6% to have fatal accidents. This result implies that bridge/culvert locations are more hazardous and risky areas than other section of roads.

Generally, bridge/culverts currently being serving have significant influence on the driving characteristics of drivers and they account a high proportion of road side traffic accident compared to their proportion in length with that of the total length of road.

5.2 Recommendations

In the discussions above, it is clear to understand influence of bridge/culvert crossings on the performance of roads. Higher traffic accident rate and lesser operating speed of drivers associated with bridge and culvert locations are not natural i.e. these problems are related with bridge and culvert design and construction problems. Based on the findings of research work and the comments provided drivers on the questionnaire interview, I recommend the following points to be taken in to consideration while designing and constructing bridges and culverts.

- Bridge and culvert crossings should be consistent in width with the approaching road section i.e. traveled lane and shoulder widths provided on the approaching road to the drainage structure crossing should be also provided on the bridge and culvert crossings.
- Extreme right and left side of the bridge and culverts constructed on deep river valleys should have strong and solid barriers that impede drivers vision to deep valley which induces psychological frustration on drives to drive on the right extreme side, which is the main factor for most collisions on bridge and culvert crossings.
- Bridges and culverts should not be designed on horizontal curves and lowest point of sag vertical curves where there is no enough clear distance to see and understand the existence of bridge and culvert locations.
- It is very important to separate bridge/culvert lanes operating in opposite direction to avoid head on collisions and any other types of collisions on bridges and culverts between vehicles operating in opposite direction.
- Sufficient horizontal clearance distance has to be provided b/n road edge and obstruction on the road side.

The other issue that has to be considered while designing these drainage structures is that economic consideration should not be the first criterion. Safety and well performance of road has to be governing factor in the process of designing geometry of bridges and culvert crossings. This because traffic accidents that will be happened on bridge and culvert crossing that has designed based on only economic considerations during the service period of the structures is many fold of construction cost of the bridge and culverts.

Generally, current bridge and culvert crossings serving have narrow widths compared to approaching road widths. Specially, most drainage structure crossings lack shoulder widths which has greater influence on traffic operation characteristics. Therefore, geometric elements of drainage structures should be designed in uniformity with the nearby road geometries and it has to meet drivers need and expectancy.

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Appendix-A

Questionnaire formats

አዲስ አበባ ሳይንስና ቴክኖሎጂ ዩንቨርስቲ

በመንገድ ምህንድስና የትምህርት ክፍል የሁለተኛ ዲግሪ የመመረቂያ ጥናት ወረቀት መረጃ መሰብሰቢያ ቅጽ

እባክዎትን ከዚህ በታች ለተዘረዘሩት ጥያቄዎች እዉነተኛ የሆነ ምላሽ በመስጠት ይተባበሩ። ምላሹን በሚሰጡበት ወቅት ስሞንም ሆነ ስልኮን አለመጻፍ ይችላሉ።

ጥያቄ-1፡ በማሽከርከር ሥራዎ ወቅት ድልድይ በሚያቋርጡበት ስዓት የማሽከርከሪያ ፍጥነትዎን ይቀንሳሉ?

ሀ. እቀንሳለሁ **ለ.** አልቀንስም

ጥያቄ-2፡ ለጥያቄ-1 መልሶ እቀንሳለሁ ከሆነ ፍጥነቴዎን እንዲቀንሱ የሚያስገድዶት ምክንያት ምንድን ነዉ?

ሀ. ድልድይ ያለበት ቦታ ስነ-ልቦናዊ ፍርሃት ስለሚፈር

ለ. ድልድዮች ከዋናዉ መንገድ ስለሚጠቡ

ሐ. ድልድይ አካባቢ በቂ የሆነ የፊት ለፊት የእይታ ርቀት ስለማይኖር

ጥያቄ-3፡ የማሽከርከሪያ ፍጥነትዎ ላይ ተፅኖ የሚያሳድሩ ድልድዮች በየትኛዉ የመንገድ ክፍል ላይ የተሠሩት ናቸዉ?

ሀ. ቀጥ ባለ የመንገድ ክፍል ላይ የተሠሩት

ለ. በጠመዝማዛ ወይም ከርቭ ቦታ ላይ የተሠሩት

ሐ. ድልድዩ ጠመዝማዛ ወይም ቀጥ ባለ የመንገድ ክፍል መገኘቱ ለቁጥ የለዉም

ጥያቄ-4፡ በማሽከርከር ሥራዎ ዘመን ምን ያህል ቀላልም ሆነ ከባድ ግጭት አጋጥሞት ያዉቃል? እባክዎትን በቁጥር ይግለጹልን? ______________________________

ጥያቄ-5፡ እባክዎትን ከላይ ከገለጹልን ካጋጠመዎት ግጭቶች ዉስጥ ድልድይ ላይ የተፈጠሩትን በቁጥር ይግለጹልን? ______________________________

ጥያቄ-6፡ ድልድይ ላይ ላጋጠመዎት ግጭት መንስኤዉ ወይም ምክንያቱ ምን ነበር?

ሀ. የድልድዩ ስፋት ማነስ

ለ. ከፊት ለፊት የሚመጣዉን ተሽከርካሪ ለማየት የሚያስችል በቂ የሆነ የእይታ ርቀት አለመኖር

ሐ. በተሽከርካሪዉ ወይም በአሽከርካሪዉ ችግር

ጥያቄ-7፡ አሁን አገልግሎት እየሰጡ ባሉ መንገዶች ላይ ያሉት ድልድዮች ለማሽከርከር ስራ ምቹና አደጋን የሚቀንሱ እንዲሆኑ መሰራት አለበት የሚሉትን የመፍትሔ ሃሳብ እባክዎትን ይግለጹልን።

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ለትብብሮ እናመሰግናለን !!

ADDIS ABABA SCIENCE & TECHNOLOGY UNIVERSITY

A Questionnaire for data collection for Thesis work for completion of MSc in Road & Transport Engineering with tittle of "Assessment of Impact of Drainage structures on highway geometric design consistency"

You are kindly requested to respond for the questions listed below based on your actual driving work experience. You are not forced to write your personal information like name and address.

Q.1. Did you reduce your driving speed while you are crossing Bridges?

☐ Yes ☐ No

Q.2. If your response for question 1 above is yes, what is the reason that forces you to reduce your driving speed? You can select more than one options.

A. Bridges locations induce psychological fear on drivers

B. Bridges are narrower than main traveled way

C. Shortage of sufficient sight distance around bridge locations

Q.3. Which Bridge locations do force you to minimize your driving speed?

A. Bridges located on Tangent section

B. Bridges located on horizontal curve

C. there is no difference with location of bridge

Q.4. How many crash accidents did you have faced during your driving work so far? Please state it in number. ______________.

Q.5. Please state number of crashes you have faced on Bridges out of the total number of crashes you have responded in question 4 above. _______________.

Q.6. What was the factor that has contributed for crashes happened on bridges?

A. lack of Bridge width

B. Lack of sufficient sight distance a head of bridge

C. Problems related with vehicle or Driver

Q.7. What is your comment on Bridges currently being serving with respect to making them comfortable for driving work and minizine crash accidents on bridge. Please state your idea briefly.

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Thank you for your kind cooperation!

Appendix-B

Speed data

Observed speed on Tangent section

Location		H. Curve (R=110m)	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.02	***35.29***
2	10	1.08	***33.33***
3	10	1.02	***35.29***
4	10	0.90	***40.00***
5	10	0.90	***40.00***
6	10	1.00	***36.00***
7	10	0.90	***40.00***
8	10	1.37	***26.28***
9	10	0.86	***41.86***
10	10	0.82	***43.90***
Vehicle Type		Mini Bus	
1	10	1.00	***36.00***
2	10	1.00	***36.00***
3	10	1.00	***36.00***
4	10	1.11	***32.43***
5	10	1.02	***35.29***
6	10	0.96	***37.50***
7	10	0.97	***37.11***
8	10	0.87	***41.38***
9	10	1.08	***33.33***
10	10	1.02	***35.29***
11	10	1.06	***33.96***
12	10	1.14	***31.58***
13	10	1.12	***32.14***
14	10	1.05	***34.29***
15	10	1.17	***30.77***
Vehicle Type		Small Truck	
1	10	1.86	***19.35***
2	10	1.27	***28.35***
3	10	1.37	***26.28***
4	10	1.23	***29.27***
5	10	1.45	***24.83***
6	10	1.44	***25.00***
7	10	1.29	***27.91***
8	10	1.39	***25.90***
9	10	1.40	***25.71***
Vehicle Type		Large Trucks	
1	10	1.77	***20.34***
2	10	1.85	***19.46***
3	10	1.92	***18.75***
4	10	2.08	***17.31***
Vehicle Type		Large Bus	
1	10	1.28	***28.13***
2	10	1.35	***26.67***
3	10	1.41	***25.53***
4	10	1.30	***27.69***
5	10	1.25	***28.80***
Vehicle Type		Truck Trailer	
1	10	2.25	***16.00***
2	10	2.43	***14.81***
3	10	2.40	***15.00***
4	10	2.34	***15.38***

Location		H. Curve (R=220m)_	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.31	***27.48***
2	10	1.38	***26.09***
3	10	1.00	***36.00***
4	10	1.14	***31.58***
5	10	1.21	***29.75***
6	10	1.18	***30.51***
7	10	1.09	***33.03***
8	10	1.10	***32.73***
9	10	1.16	***31.03***
10	10	1.06	***33.96***
Vehicle Type		Mini Bus	
1	10	1.25	***28.80***
2	10	1.25	***28.80***
3	10	1.11	***32.43***
4	10	1.00	***36.00***
5	10	1.18	***30.51***
6	10	1.00	***36.00***
7	10	1.00	***36.00***
8	10	1.21	***29.75***
9	10	1.25	***28.80***
10	10	1.23	***29.27***
11	10	1.15	***31.30***
12	10	1.07	***33.64***
13	10	1.09	***33.03***
14	10	1.12	***32.14***
15	10	1.20	***30.00***
Vehicle Type		Small Truck	
1	10	1.25	***28.80***
2	10	1.60	***22.50***
3	10	1.38	***26.09***
4	10	1.45	***24.83***
5	10	1.32	***27.27***
6	10	1.54	***23.38***
7	10	1.42	***25.35***
8	10	1.40	***25.71***
9	10	1.36	***26.47***
Vehicle Type		Large Trucks	
1	10	1.38	***26.09***
2	10	1.78	***20.22***
3	10	2.14	***16.82***
4	10	1.85	***19.46***
Vehicle Type		Large Bus	
1	10	1.32	***27.27***
2	10	1.26	***28.57***
3	10	1.33	***27.07***
4	10	1.45	***24.83***
5	10	1.38	***26.09***
Vehicle Type		Truck Trailer	
1	10	2.09	***17.22***
2	10	1.77	***20.34***
3	10	2.15	***16.74***
4	10	2.20	***16.36***

Observed speed on Horizontal curves

Location		H. Curve (R=120m)__			Location		H. Curve (R=100m)____	
No	Distance(m)	Time(se)	Speed(Km/hr.)		No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		Automobile			Vehicle Type		Automobile	
1	10	1.10	32.73		1	10	1.00	36.00
2	10	1.10	32.73		2	10	1.00	36.00
3	10	1.00	36.00		3	10	1.05	34.29
4	10	1.24	29.03		4	10	1.00	36.00
5	10	1.15	31.30		5	10	1.00	36.00
6	10	1.21	29.75		6	10	1.28	28.13
7	10	1.12	32.14		7	10	1.09	33.03
8	10	1.22	29.51		8	10	1.00	36.00
9	10	1.13	31.86		9	10	1.27	28.35
10	10	1.17	30.77		10	10	1.13	31.86
Vehicle Type		Mini Bus			Vehicle Type		Mini Bus	
1	10	1.30	27.69		1	10	1.38	26.09
2	10	1.22	29.51		2	10	1.36	26.47
3	10	1.25	28.80		3	10	1.18	30.51
4	10	1.23	29.27		4	10	1.14	31.58
5	10	1.34	26.87		5	10	1.04	34.62
6	10	1.33	27.07		6	10	1.06	33.96
7	10	1.33	27.07		7	10	1.04	34.62
8	10	1.30	27.69		8	10	1.14	31.58
9	10	1.20	30.00		9	10	1.16	31.03
10	10	1.20	30.00		10	10	1.12	32.14
11	10	1.21	29.75		11	10	1.00	36.00
12	10	1.31	27.48		12	10	1.18	30.51
13	10	1.20	30.00		13	10	1.08	33.33
14	10	1.21	29.75		14	10	1.20	30.00
15	10	1.20	30.00		15	10	1.23	29.27
Vehicle Type		Small Truck			Vehicle Type		Small Truck	
1	10	1.43	25.17		1	10	1.33	27.07
2	10	1.39	25.90		2	10	2.40	15.00
3	10	1.37	26.28		3	10	1.33	27.07
4	10	1.44	25.00		4	10	1.69	21.30
5	10	1.45	24.83		5	10	1.43	25.17
6	10	1.41	25.53		6	10	2.14	16.82
7	10	1.40	25.71		7	10	1.89	19.05
8	10	1.40	25.71		8	10	1.87	19.25
9	10	1.46	24.66		9	10	2.40	15.00
Vehicle Type		Large Truck			Vehicle Type		Large Trucks	
1	10	1.90	18.95		1	10	2.14	16.82
2	10	2.00	18.00		2	10	1.89	19.05
3	10	1.86	19.35		3	10	1.87	19.25
4	10	1.76	20.45		4	10	2.40	15.00
Vehicle Type		Large Bus			Vehicle Type		Large Bus	
1	10	1.42	25.35		1	10	1.34	26.87
2	10	1.58	22.78		2	10	1.22	29.51
3	10	1.73	20.81		3	10	1.40	25.71
4	10	1.76	20.45		4	10	1.35	26.67
5	10	1.69	21.30		5	10	1.28	28.13
Vehicle Type		Truck Trailer			Vehicle Type		Truck Trailer	
1	10	2.10	17.14		1	10	2.40	15.00
2	10	2.35	15.32		2	10	2.38	15.13
3	10	2.44	14.75		3	10	2.43	14.81
4	10	2.26	15.93	###	4	10	2.35	15.32

Location		H. Curve (R=200m)__	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Automobile**	
1	10	0.96	***37.50***
2	10	1.08	***33.33***
3	10	1.21	***29.75***
4	10	1.12	***32.14***
5	10	1.14	***31.58***
6	10	1.03	***34.95***
7	10	1.05	***34.29***
8	10	1.00	***36.00***
9	10	1.08	***33.33***
10	10	1.18	***30.51***
Vehicle Type		**Mini Bus**	
1	10	1.20	***30.00***
2	10	1.24	***29.03***
3	10	1.09	***33.03***
4	10	1.11	***32.43***
5	10	1.13	***31.86***
6	10	1.17	***30.77***
7	10	0.98	***36.73***
8	10	1.00	***36.00***
9	10	0.89	***40.45***
10	10	1.14	***31.58***
11	10	1.23	***29.27***
12	10	1.27	***28.35***
13	10	1.17	***30.77***
14	10	1.24	***29.03***
15	10	1.28	***28.13***

Location		H. Curve (R=200m)__	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Small Truck**	
1	10	1.26	***28.57***
2	10	1.52	***23.68***
3	10	1.43	***25.17***
4	10	1.38	***26.09***
5	10	1.39	***25.90***
6	10	1.57	***22.93***
7	10	1.66	***21.69***
8	10	1.42	***25.35***
9	10	1.33	***27.07***
Vehicle Type		**Large Trucks**	
1	10	1.37	***26.28***
2	10	1.87	***19.25***
3	10	1.91	***18.85***
4	10	1.77	***20.34***
Vehicle Type		**Large Bus**	
1	10	1.33	***27.07***
2	10	1.28	***28.13***
3	10	1.31	***27.48***
4	10	1.33	***27.07***
5	10	1.24	***29.03***
Vehicle Type		**Truck Trailer**	
1	10	2.01	***17.91***
2	10	1.85	***19.46***
3	10	1.93	***18.65***
4	10	1.78	***20.22***

Observed speed data on Tangent section

Location		Tangent section __1__	
No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		Automobile	
1	10	0.66	***54.55***
2	10	0.90	***40.00***
3	10	0.72	***50.00***
4	10	0.53	***67.92***
5	10	0.86	***41.86***
6	10	0.93	***38.71***
7	10	0.79	***45.57***
8	10	0.66	***54.55***
9	10	0.68	***52.94***
10	10	0.70	***51.43***
Vehicle Type		Mini Bus	
1	10	0.79	***45.57***
2	10	0.79	***45.57***
3	10	0.72	***50.00***
4	10	0.53	***67.92***
5	10	0.66	***54.55***
6	10	0.53	***67.92***
7	10	0.90	***40.00***
8	10	0.79	***45.57***
9	10	0.59	***61.02***
10	10	0.79	***45.57***
11	10	0.79	***45.57***
12	10	0.72	***50.00***
13	10	0.81	***44.44***
14	10	0.69	***52.17***
15	10	0.73	***49.32***
Vehicle Type		Small Truck	
1	10	0.79	***45.57***
2	10	0.98	***36.73***
3	10	1.09	***33.03***
4	10	0.86	***41.86***
5	10	0.96	***37.50***
6	10	0.86	***41.86***
7	10	0.95	***37.89***
8	10	1.12	***32.14***
9	10	1.05	***34.29***
Vehicle Type		Large Trucks	
1	10	1.13	***31.86***
2	10	0.90	***40.00***
3	10	1.03	***34.95***
4	10	0.88	***40.91***
Vehicle Type		Large Bus	
1	10	1.00	***36.00***
2	10	0.85	***42.35***
3	10	0.76	***47.37***
4	10	0.98	***36.73***
5	10	0.82	***43.90***
Vehicle Type		Truck Trailer	
1	10	1.18	***30.51***
2	10	1.05	***34.29***
3	10	1.22	***29.51***
4	10	1.20	***30.00***

Location		Tangent Section __2__	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	0.56	***64.29***
2	10	0.75	***48.00***
3	10	0.56	***64.29***
4	10	0.85	***42.35***
5	10	0.74	***48.65***
6	10	0.65	***55.38***
7	10	0.66	***54.55***
8	10	0.71	***50.70***
9	10	0.76	***47.37***
10	10	0.8	***45.00***
Vehicle Type		Mini Bus	
1	10	0.72	***50.00***
2	10	0.88	***40.91***
3	10	0.72	***50.00***
4	10	0.98	***36.73***
5	10	0.79	***45.57***
6	10	0.99	***36.36***
7	10	0.79	***45.57***
8	10	0.84	***42.86***
9	10	0.95	***37.89***
10	10	0.88	***40.91***
11	10	0.88	***40.91***
12	10	0.81	***44.44***
13	10	0.73	***49.32***
14	10	0.74	***48.65***
15	10	0.72	***50.00***
Vehicle Type		Small Truck	
1	10	0.78	***46.15***
2	10	0.86	***41.86***
3	10	0.95	***37.89***
4	10	0.97	***37.11***
5	10	1.02	***35.29***
6	10	0.98	***36.73***
7	10	1.03	***34.95***
8	10	1.07	***33.64***
9	10	0.82	***43.90***
Vehicle Type		Large Trucks	
1	10	1.16	***31.03***
2	10	1.11	***32.43***
3	10	0.89	***40.45***
4	10	1.05	***34.29***
Vehicle Type		Large Bus	
1	10	0.87	***41.38***
2	10	0.93	***38.71***
3	10	0.86	***41.86***
4	10	1.04	***34.62***
5	10	0.86	***41.86***
Vehicle Type		Truck Trailer	
1	10	1.12	***32.14***
2	10	1.21	***29.75***
3	10	1.18	***30.51***
4	10	1.24	***29.03***

Observed Speed data on Bridge/Culverts at tangent alignment

Location		Bridge (tangent) __1_	
No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		Automobile	
1	10	1.25	28.80
2	10	1.15	31.30
3	10	1.18	30.51
4	10	1.16	31.03
5	10	1.21	29.75
6	10	1.31	27.48
7	10	1.25	28.80
8	10	1.24	29.03
9	10	0.98	36.73
10	10	1.26	28.57
Vehicle Type		Mini Bus	
1	10	1.23	29.27
2	10	1.09	33.03
3	10	1.28	28.13
4	10	1.33	27.07
5	10	1.26	28.57
6	10	1.11	32.43
7	10	1.23	29.27
8	10	1.33	27.07
9	10	1.37	26.28
10	10	1.34	26.87
11	10	1.22	29.51
12	10	1.28	28.13
13	10	1.35	26.67
14	10	1.27	28.35
15	10	1.20	30.00
Vehicle Type		Small Truck	
1	10	1.46	24.66
2	10	1.52	23.68
3	10	1.40	25.71
4	10	1.78	20.22
5	10	1.62	22.22
6	10	1.72	20.93
7	10	1.47	24.49
8	10	1.67	21.56
9	10	1.36	26.47
Vehicle Type		Large Trucks	
1	10	1.78	20.22
2	10	1.82	19.78
3	10	1.76	20.45
4	10	1.72	20.93
Vehicle Type		Large Bus	
1	10	1.48	24.32
2	10	1.62	22.22
3	10	1.38	26.09
4	10	1.42	25.35
5	10	1.66	21.69
Vehicle Type		Truck Trailer	
1	10	1.78	20.22
2	10	1.86	19.35
3	10	1.92	18.75
4	10	1.82	19.78

Location		Bridge(tangent) 2_	
No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		Automobile	
1	10	1.13	31.86
2	10	1.09	33.03
3	10	1.24	29.03
4	10	1.23	29.27
5	10	1.24	29.03
6	10	1.24	29.03
7	10	1.32	27.27
8	10	1.22	29.51
9	10	1.18	30.51
10	10	1.21	29.75
Vehicle Type		Mini Bus	
1	10	1.06	33.96
2	10	1.12	32.14
3	10	1.33	27.07
4	10	1.24	29.03
5	10	1.32	27.27
6	10	1.25	28.80
7	10	1.36	26.47
8	10	1.37	26.28
9	10	1.14	31.58
10	10	1.22	29.51
11	10	1.20	30.00
12	10	1.33	27.07
13	10	1.33	27.07
14	10	1.28	28.13
15	10	1.34	26.87
Vehicle Type		Small Truck	
1	10	1.28	28.13
2	10	1.34	26.87
3	10	1.44	25.00
4	10	1.42	25.35
5	10	1.66	21.69
6	10	1.54	23.38
7	10	1.46	24.66
8	10	1.37	26.28
9	10	1.44	25.00
Vehicle Type		Large Trucks	
1	10	1.66	21.69
2	10	1.69	21.30
3	10	1.72	20.93
4	10	1.86	19.35
Vehicle Type		Large Bus	
1	10	1.36	26.47
2	10	1.42	25.35
3	10	1.58	22.78
4	10	1.68	21.43
5	10	1.44	25.00
Vehicle Type		Truck Trailer	
1	10	1.72	20.93
2	10	1.87	19.25
3	10	1.92	18.75
4	10	1.75	20.57

Location		Bridge(tangent) __3_	
No	Distance	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.18	***30.51***
2	10	1.20	***30.00***
3	10	1.24	***29.03***
4	10	1.33	***27.07***
5	10	1.21	***29.75***
6	10	1.32	***27.27***
7	10	1.37	***26.28***
8	10	1.25	***28.80***
9	10	1.22	***29.51***
10	10	1.33	***27.07***
Vehicle Type		Mini Bus	
1	10	1.14	***31.58***
2	10	1.23	***29.27***
3	10	1.31	***27.48***
4	10	1.33	***27.07***
5	10	1.33	***27.07***
6	10	1.25	***28.80***
7	10	1.18	***30.51***
8	10	1.37	***26.28***
9	10	1.21	***29.75***
10	10	1.16	***31.03***
11	10	1.23	***29.27***
12	10	1.28	***28.13***
13	10	1.31	***27.48***
14	10	1.24	***29.03***
15	10	1.27	***28.35***
Vehicle Type		Small Truck	
1	10	1.30	***27.69***
2	10	1.44	***25.00***
3	10	1.66	***21.69***
4	10	1.37	***26.28***
5	10	1.72	***20.93***
6	10	1.42	***25.35***
7	10	1.62	***22.22***
8	10	1.56	***23.08***
9	10	1.53	***23.53***
Vehicle Type		Large Trucks	
1	10	1.71	***21.05***
2	10	1.88	***19.15***
3	10	1.75	***20.57***
4	10	1.82	***19.78***
Vehicle Type		Large Bus	
1	10	1.47	***24.49***
2	10	1.61	***22.36***
3	10	1.45	***24.83***
4	10	1.72	***20.93***
5	10	1.88	***19.15***
Vehicle Type		Truck Trailer	
1	10	1.75	***20.57***
2	10	1.68	***21.43***
3	10	1.82	***19.78***
4	10	1.91	***18.85***

Location		Culvert (tangent) 1__	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.21	***29.75***
2	10	1.18	***30.51***
3	10	1.24	***29.03***
4	10	1.15	***31.30***
5	10	1.24	***29.03***
6	10	1.19	***30.25***
7	10	1.20	***30.00***
8	10	1.23	***29.27***
9	10	1.22	***29.51***
10	10	1.17	***30.77***
Vehicle Type		Mini Bus	
1	10	1.20	***30.00***
2	10	1.33	***27.07***
3	10	1.32	***27.27***
4	10	1.27	***28.35***
5	10	1.19	***30.25***
6	10	1.27	***28.35***
7	10	1.26	***28.57***
8	10	1.26	***28.57***
9	10	1.21	***29.75***
10	10	1.30	***27.69***
11	10	1.29	***27.91***
12	10	1.24	***29.03***
13	10	1.28	***28.13***
14	10	1.29	***27.91***
15	10	1.21	***29.75***
Vehicle Type		Small Truck	
1	10	1.39	***25.90***
2	10	1.41	***25.53***
3	10	1.36	***26.47***
4	10	1.38	***26.09***
5	10	1.42	***25.35***
6	10	1.44	***25.00***
7	10	1.56	***23.08***
8	10	1.44	***25.00***
9	10	1.39	***25.90***
Vehicle Type		Large Trucks	
1	10	1.74	***20.69***
2	10	1.79	***20.11***
3	10	1.82	***19.78***
4	10	1.73	***20.81***
Vehicle Type		Large Bus	
1	10	1.58	***22.78***
2	10	1.66	***21.69***
3	10	1.64	***21.95***
4	10	1.69	***21.30***
5	10	1.72	***20.93***
Vehicle Type		Truck Trailer	
1	10	1.92	***18.75***
2	10	1.88	***19.15***
3	10	1.79	***20.11***
4	10	1.85	***19.46***

Location		Culvert (tangent) 2	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Automobile**	
1	10	1.19	***30.25***
2	10	1.14	***31.58***
3	10	1.30	***27.69***
4	10	1.27	***28.35***
5	10	1.18	***30.51***
6	10	1.28	***28.13***
7	10	1.25	***28.80***
8	10	1.21	***29.75***
9	10	1.18	***30.51***
10	10	1.28	***28.13***
Vehicle Type		**Mini Bus**	
1	10	1.18	***30.51***
2	10	1.17	***30.77***
3	10	1.20	***30.00***
4	10	1.31	***27.48***
5	10	1.25	***28.80***
6	10	1.28	***28.13***
7	10	1.30	***27.69***
8	10	1.34	***26.87***
9	10	1.29	***27.91***
10	10	1.31	***27.48***
11	10	1.32	***27.27***
12	10	1.28	***28.13***
13	10	1.27	***28.35***
14	10	1.24	***29.03***
15	10	1.31	***27.48***

Location		Culvert (tangent) 2	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Small Truck**	
1	10	1.44	***25.00***
2	10	1.48	***24.32***
3	10	1.52	***23.68***
4	10	1.54	***23.38***
5	10	1.42	***25.35***
6	10	1.38	***26.09***
7	10	1.39	***25.90***
8	10	1.41	***25.53***
9	10	1.46	***24.66***
Vehicle Type		**Large Trucks**	
1	10	1.84	***19.57***
2	10	1.80	***20.00***
3	10	1.77	***20.34***
4	10	1.76	***20.45***
Vehicle Type		**Large Bus**	
1	10	1.8	***20.00***
2	10	1.84	***19.57***
3	10	1.76	***20.45***
4	10	1.83	***19.67***
5	10	1.80	***20.00***
Vehicle Type		**Truck Trailer**	
1	10	1.81	***19.89***
2	10	1.78	***20.22***
3	10	1.83	***19.67***
4	10	1.77	***20.34***

Observed speed data on Bridges/culverts at Horizontal curves

Location		Culvert on H.Curve (R=85m)	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.66	***21.69***
2	10	1.56	***23.08***
3	10	1.74	***20.69***
4	10	1.68	***21.43***
5	10	1.75	***20.57***
6	10	1.67	***21.56***
7	10	1.74	***20.69***
8	10	1.64	***21.95***
9	10	1.68	***21.43***
10	10	1.77	***20.34***
Vehicle Type		Mini Bus	
1	10	1.65	***21.82***
2	10	1.71	***21.05***
3	10	1.74	***20.69***
4	10	1.76	***20.45***
5	10	1.58	***22.78***
6	10	1.66	***21.69***
7	10	1.78	***20.22***
8	10	1.66	***21.69***
9	10	1.72	***20.93***
10	10	1.69	***21.30***
11	10	1.70	***21.18***
12	10	1.67	***21.56***
13	10	1.75	***20.57***
14	10	1.78	***20.22***
15	10	1.59	***22.64***
Vehicle Type		Small Truck	
1	10	1.82	***19.78***
2	10	1.75	***20.57***
3	10	1.81	***19.89***
4	10	1.82	***19.78***
5	10	1.85	***19.46***
6	10	1.84	***19.57***
7	10	1.86	***19.35***
8	10	1.79	***20.11***
9	10	1.88	***19.15***
Vehicle Type		Large Trucks	
1	10	2.56	***14.06***
2	10	2.45	***14.69***
3	10	2.51	***14.34***
4	10	2.45	***14.69***
Vehicle Type		Large Bus	
1	10	1.77	***20.34***
2	10	1.82	***19.78***
3	10	1.85	***19.46***
4	10	1.85	***19.46***
5	10	1.82	***19.78***
Vehicle Type		Truck Trailer	
1	10	2.66	***13.53***
2	10	2.41	***14.94***
3	10	2.52	***14.29***
4	10	2.62	***13.74***

Location		Culvert on H.Curve (R=180m)	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		Automobile	
1	10	1.41	***25.53***
2	10	1.32	***27.27***
3	10	1.47	***24.49***
4	10	1.44	***25.00***
5	10	1.42	***25.35***
6	10	1.38	***26.09***
7	10	1.47	***24.49***
8	10	1.52	***23.68***
9	10	1.22	***29.51***
10	10	1.37	***26.28***
Vehicle Type		Mini Bus	
1	10	1.51	***23.84***
2	10	1.34	***26.87***
3	10	1.44	***25.00***
4	10	1.42	***25.35***
5	10	1.48	***24.32***
6	10	1.31	***27.48***
7	10	1.45	***24.83***
8	10	1.40	***25.71***
9	10	1.38	***26.09***
10	10	1.41	***25.53***
11	10	1.38	***26.09***
12	10	1.42	***25.35***
13	10	1.34	***26.87***
14	10	1.44	***25.00***
15	10	1.41	***25.53***
Vehicle Type		Small Truck	
1	10	1.78	***20.22***
2	10	1.77	***20.34***
3	10	1.80	***20.00***
4	10	1.81	***19.89***
5	10	1.75	***20.57***
6	10	1.80	***20.00***
7	10	1.81	***19.89***
8	10	1.80	***20.00***
9	10	1.71	***21.05***
Vehicle Type		Large Trucks	
1	10	2.1	***17.14***
2	10	2.15	***16.74***
3	10	2.08	***17.31***
4	10	1.96	***18.37***
Vehicle Type		Large Bus	
1	10	1.65	***21.82***
2	10	1.66	***21.69***
3	10	1.72	***20.93***
4	10	1.68	***21.43***
5	10	1.70	***21.18***
Vehicle Type		Truck Trailer	
1	10	2.25	***16.00***
2	10	2.33	***15.45***
3	10	2.19	***16.44***
4	10	2.23	***16.14***

Location		Bridge on H.Curve (R=120m)	
No	Distance(m)	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Automobile**	
1	10	1.38	***26.09***
2	10	1.44	***25.00***
3	10	1.36	***26.47***
4	10	1.42	***25.35***
5	10	1.42	***25.35***
6	10	1.54	***23.38***
7	10	1.31	***27.48***
8	10	1.29	***27.91***
9	10	1.44	***25.00***
10	10	1.33	***27.07***
Vehicle Type		**Mini Bus**	
1	10	1.55	***23.23***
2	10	1.38	***26.09***
3	10	1.47	***24.49***
4	10	1.52	***23.68***
5	10	1.41	***25.53***
6	10	1.37	***26.28***
7	10	1.33	***27.07***
8	10	1.32	***27.27***
9	10	1.36	***26.47***
10	10	1.39	***25.90***
11	10	1.34	***26.87***
12	10	1.28	***28.13***
13	10	1.33	***27.07***
14	10	1.29	***27.91***
15	10	1.31	***27.48***
Vehicle Type		**Small Truck**	
1	10	1.77	***20.34***
2	10	1.81	***19.89***
3	10	1.65	***21.82***
4	10	1.66	***21.69***
5	10	1.49	***24.16***
6	10	1.38	***26.09***
7	10	1.42	***25.35***
8	10	1.47	***24.49***
9	10	1.66	***21.69***
Vehicle Type		**Large Trucks**	
1	10	1.8	***20.00***
2	10	1.71	***21.05***
3	10	1.84	***19.57***
4	10	1.78	***20.22***
Vehicle Type		**Large Bus**	
1	10	1.41	***25.53***
2	10	1.39	***25.90***
3	10	1.54	***23.38***
4	10	1.66	***21.69***
5	10	1.44	***25.00***
Vehicle Type		**Truck Trailer**	
1	10	1.89	***19.05***
2	10	1.96	***18.37***
3	10	2.18	***16.51***
4	10	2.11	***17.06***

Location		Bridge on H.Curve (R=100m)	
No	Distance	Time(se)	*Speed(Km/hr.)*
Vehicle Type		**Automobile**	
1	10	1.56	***23.08***
2	10	1.48	***24.32***
3	10	1.39	***25.90***
4	10	1.48	***24.32***
5	10	1.52	***23.68***
6	10	1.58	***22.78***
7	10	1.48	***24.32***
8	10	1.53	***23.53***
9	10	1.54	***23.38***
10	10	1.47	***24.49***
Vehicle Type		**Mini Bus**	
1	10	1.45	***24.83***
2	10	1.51	***23.84***
3	10	1.47	***24.49***
4	10	1.38	***26.09***
5	10	1.34	***26.87***
6	10	1.45	***24.83***
7	10	1.42	***25.35***
8	10	1.42	***25.35***
9	10	1.52	***23.68***
10	10	1.41	***25.53***
11	10	1.40	***25.71***
12	10	1.41	***25.53***
13	10	1.48	***24.32***
14	10	1.48	***24.32***
15	10	1.42	***25.35***
Vehicle Type		**Small Truck**	
1	10	1.72	***20.93***
2	10	1.48	***24.32***
3	10	1.76	***20.45***
4	10	1.82	***19.78***
5	10	1.44	***25.00***
6	10	1.77	***20.34***
7	10	1.48	***24.32***
8	10	1.54	***23.38***
9	10	1.62	***22.22***
Vehicle Type		**Large Trucks**	
1	10	1.82	***19.78***
2	10	1.79	***20.11***
3	10	1.85	***19.46***
4	10	1.80	***20.00***
Vehicle Type		**Large Bus**	
1	10	1.65	***21.82***
2	10	1.58	***22.78***
3	10	1.60	***22.50***
4	10	1.55	***23.23***
5	10	1.68	***21.43***
Vehicle Type		**Truck Trailer**	
1	10	2.24	***16.07***
2	10	2.10	***17.14***
3	10	1.99	***18.09***
4	10	2.22	***16.22***

Location		Bridge on H.Curve (R=200m)	
No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		**Automobile**	
1	10	1.20	***30.00***
2	10	1.21	***29.75***
3	10	1.22	***29.51***
4	10	1.18	***30.51***
5	10	1.09	***33.03***
6	10	1.24	***29.03***
7	10	1.26	***28.57***
8	10	1.20	***30.00***
9	10	1.08	***33.33***
10	10	1.27	***28.35***
Vehicle Type		**Mini Bus**	
1	10	1.28	***28.13***
2	10	1.33	***27.07***
3	10	1.38	***26.09***
4	10	1.34	***26.87***
5	10	1.37	***26.28***
6	10	1.25	***28.80***
7	10	1.34	***26.87***
8	10	1.29	***27.91***
9	10	1.27	***28.35***
10	10	1.26	***28.57***
11	10	1.27	***28.35***
12	10	1.35	***26.67***
13	10	1.36	***26.47***
14	10	1.36	***26.47***
15	10	1.36	***26.47***

Location		Bridge on H.Curve (R=200m)	
No	Distance(m)	Time(se)	Speed(Km/hr.)
Vehicle Type		**Small Truck**	
1	10	1.36	***26.47***
2	10	1.44	***25.00***
3	10	1.42	***25.35***
4	10	1.52	***23.68***
5	10	1.35	***26.67***
6	10	1.66	***21.69***
7	10	1.78	***20.22***
8	10	1.69	***21.30***
9	10	1.47	***24.49***
Vehicle Type		**Large Trucks**	
1	10	1.74	***20.69***
2	10	1.88	***19.15***
3	10	1.96	***18.37***
4	10	1.84	***19.57***
Vehicle Type		**Large Bus**	
1	10	1.40	***25.71***
2	10	1.53	***23.53***
3	10	1.66	***21.69***
4	10	1.62	***22.22***
5	10	1.48	***24.32***
Vehicle Type		**Truck Trailer**	
1	10	2.09	***17.22***
2	10	2.11	***17.06***
3	10	2.18	***16.51***
4	10	2.22	***16.22***

Appendix-C

Federal Roads' Crash data

Year	Annual Traffic accident report by accident severity and location for Federal roads					
	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
2002	1.Pure Tangent	308	586	552	4,213	5,659
	2. Tangent with side hill or valley	4	15	30	160	209
	3. Tangent with uneven surface	0	3	4	18	25
	4. Horizontal curve	0	2	10	101	113
	5. UP ahill	0	2	16	54	72
	6. Down a valley	1	0	1	1	3
	7. Bridges& Culverts	10	13	39	142	204
	Total	323	621	652	4,689	6,285
	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
2003	1.Pure Tangent	260	805	731	5,808	7,604
	2. Tangent with side hill or valley	13	17	25	448	503
	3. Tangent with uneven surface	0	4	5	62	71
	4. Horizontal curve	0	14	10	130	154
	5. UP ahill	24	17	0	280	321
	6. Down a valley	19	38	40	315	412
	7. Bridges& Culverts	16	9	20	24	69
	Total	332	904	831	7,067	9,134
	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
2004	1.Pure Tangent	320	1,026	659	8,208	10,213
	2. Tangent with side hill or valley	4	48	52	258	362
	3. Tangent with uneven surface	10	9	4	83	106
	4. Horizontal curve	3	10	3	115	131
	5. UP ahill	6	36	37	224	303
	6. Down a valley	14	46	52	179	291
	7. Bridges& Culverts	12	15	13	83	123
	Total	369	1,190	820	9,150	11,529

Year	Annual Traffic accident report by accident severity and location for Federal roads					
2005	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
	1.Pure Tangent	320	1,105	1,032	11,026	***13,483***
	2. Tangent with side hill or valley	2	42	43	453	***540***
	3. Tangent with uneven surface	2	23	26	217	***268***
	4. Horizontal curve	12	59	42	341	***454***
	5. UP ahill	5	35	45	315	***400***
	6. Down a valley	18	66	66	417	***567***
	7. Bridges& Culverts	8	6	9	80	***103***
	Total	***367***	***1,336***	***1,263***	***12,849***	***15,815***
2006	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
	1.Pure Tangent	245	1,284	959	13,082	***15,570***
	2. Tangent with side hill or valley	30	55	31	585	***701***
	3. Tangent with uneven surface	9	3	14	130	***156***
	4. Horizontal curve	33	17	23	316	***389***
	5. UP ahill	16	40	43	345	***444***
	6. Down a valley	25	61	56	320	***462***
	7. Bridges& Culverts	33	24	2	123	***182***
	Total	***391***	***1,484***	***1,128***	***14,901***	***17,904***
2007	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	Incapacitating	Light Crash	Property Damage	
	1.Pure Tangent	303	1,439	847	14,780	***17,369***
	2. Tangent with side hill or valley	27	66	43	804	***940***
	3. Tangent with uneven surface	18	31	16	260	***325***
	4. Horizontal curve	29	60	34	791	***914***
	5. UP ahill	10	10	76	443	***539***
	6. Down a valley	18	60	62	-	***140***
	7. Bridges& Culverts	11	3	20	171	***205***
	Total	***416***	***1,669***	***1,098***	***17,249***	***20,432***

Crash data for Kombolcha – Dessie Road section

Year	Kombolcha to Dessie road annual Traffic accident report by accident severity and location					
	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	*Incapacitating*	*Light Crash*	*Property Damage*	
2006	1.Pure Tangent	16	23	37	20	*96*
	2. Tangent with side hill or valley	1	2	1	1	*5*
	3. Tangent with uneven surface	0	0	2	0	*2*
	4. Horizontal curve	0	0	1	0	*1*
	5. UP ahill	0	0	0	0	*0*
	6. Down a valley	0	1	0	0	*1*
	7. Bridges& Culverts	1	2	0	3	*6*
	Total	*18*	*28*	*41*	*24*	*111*
2007	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	*Incapacitating*	*Light Crash*	*Property Damage*	
	1.Pure Tangent	10	9	29	14	*62*
	2. Tangent with side hill or valley	1	0	0	4	*5*
	3. Tangent with uneven surface	0	0	1	0	*1*
	4. Horizontal curve	0	0	1	2	*3*
	5. UP ahill	0	0	0	0	*0*
	6. Down a valley	0	0	0	0	*0*
	7. Bridges& Culverts	1	0		0	*1*
	Total	*12*	*9*	*31*	*20*	*72*
2008	Road geometric characteristics	Frequency of accident by severity				Total
		Fatality	*Incapacitating*	*Light Crash*	*Property Damage*	
	1.Pure Tangent	7	4	4	48	*63*
	2. Tangent with side hill or valley	1	1	2	0	*4*
	3. Tangent with uneven surface	0	0	0	0	*0*
	4. Horizontal curve	0	0	3	7	*10*
	5. UP ahill	0	0	0	0	*0*
	6. Down a valley	2	0	0	2	*4*
	7. Bridges& Culverts	1	0	0	5	*6*
	Total	*11*	*5*	*9*	*62*	*87*

Appendix-D

Questionnaire response Summery sheet

Driver's Questionnaire response data sheet																			
No	A		B			C			Crash history		Cause for on Bridge crashes			Comments on current bridges					
	Yes	No	1'	2'	3'	a'	b'	c'	Total	On Bridge	α	β	μ	i	ii	iii	iv	v	vi
1	√			√			√								√		√		
2	√			√				√	0	0				√			√		
3	√			√			√		1							√	√		
4	√			√				√	1	1			√	√					√
5	√				√		√		0	0				√					
6	√			√			√		0	0				√			√		
7	√			√			√		0	0							√		
8	√			√			√		2	0				√				√	
9	√			√			√		0	0				√					√
10	√			√			√		1					√					√
11	√			√			√												√
12	√			√			√		2	1	√			√					√
13	√			√			√		2	1	√			√			√	√	√
14	√			√		√									√	√		√	
15	√			√			√							√			√		
16	√			√			√												√
17	√			√			√		1					√					√
18	√			√			√		4	2			√		√	√			
19	√			√			√							√		√		√	√
20	√			√			√							√		√			
21	√			√			√				√			√			√		√
22	√			√			√		1	0				√			√		√
23	√			√				√						√		√	√		
24	√			√			√		2	0						√	√		
25	√			√			√							√			√		√
26	√			√				√	0	0				√					√
27	√			√				√						√		√			
28	√				√		√					√					√		√
29	√			√			√		1					√					
30	√			√			√							√		√		√	
31	√			√			√										√		√
32	√				√		√							√					√
33	√			√			√							√		√			
34	√			√			√		0	0							√		√
35	√			√			√							√		√			
36	√			√			√												√
37	√			√			√							√		√			√
38	√			√			√		2	2	√			√					√
39	√			√			√		1	0				√			√		
40	√			√				√	0	0				√					
41	√			√			√		1	0				√					√
42	√			√			√		1	0									√
43	√		√					√	0	0				√			√		
44	√				√		√		0	0				√					√
45	√				√		√		0	0		√							

Driver's Questionnaire response data sheet

No	A		B			C			Crash history		Cause for on Bridge crashes			Comments on current bridges					
	Yes	No	1'	2'	3'	a'	b'	c'	Total	On Bridge	α	β	μ	i	ii	iii	iv	v	vi
46	√			√				√			√			√				√	
47	√				√		√					√		√					
48	√				√		√		0	0		√		√					√
49	√		√				√		0	0	√	√		√				√	√
50	√			√			√		0	0		√					√		
51	√			√			√		0	0	√	√		√			√		√
52	√		√				√		3	1	√			√					
53	√			√			√		2	2		√							
54	√		√				√		0	0		√					√		
55	√		√		√			√	2	1			√						
56	√				√		√		3	2		√		√					√
57	√				√		√		2	2		√		√					√
58	√			√			√		6	5	√	√							
59	√			√		√			0	0									
60	√				√			√	0	0									√
61	√		√				√		4	3		√							√
62	√		√				√		3	2		√		√					√
63	√		√				√		1	0		√							√
64	√			√			√		0	0									
65	√			√			√		2	0			√	√					√
66	√				√		√		2	2		√					√		
67	√				√		√		4	3		√		√					√
68	√				√		√		0	0				√			√		
69	√		√			√			6	2	√			√				√	√
70	√				√			√	0	0		√							
71	√				√		√		3	1			√						√
72	√			√			√		2	0	√			√					
73	√			√			√		3	1			√	√		√			√
74	√			√			√		3	2		√							
75		√	√				√		0	0									
76	√			√			√		3	0				√					√
77	√		√				√		2	0							√		
78	√				√		√		2	2		√		√			√		
79		√															√	√	
80	√			√			√		3	1		√		√					√
81	√			√			√		5	2		√							√
82	√				√		√		1	0		√		√					√
83		√		√				√	2	1	√						√		
84	√			√				√	0	0				√			√		
85	√			√			√		0	0				√					
86	√			√				√	5	1		√		√					√
87	√			√			√		0	0				√			√		
88	√			√	√		√		0	0				√			√		√
89	√			√			√		0	0				√				√	
90	√			√				√	0	0									√
91	√			√			√		1	0						√			
92	√			√				√				√				√	√		
93	√			√			√										√		
94	√			√			√							√			√		
95	√			√			√		0	0				√					√
96	√		√				√		3	1	√								√
97	√		√				√		0	0				√		√	√		
98	√			√	√		√		5	1		√	√			√			
99	√			√			√		4	1	√		√						
100	√				√		√		0	0				√					√
101	√			√				√	1	0				√			√		√
102	√			√			√		0	0									
103	√			√			√		0	0									
Tot.	**100**	**3**	**13**	**71**	**21**	**3**	**82**	**17**	**111**	**46**	**14**	**26**	**8**	**61**	**3**	**17**	**34**	**10**	**48**

Symbol	Description
A	Did you reduce your driving speed while you are crossing Bridges?
B	If your response for question 1 above is yes, what is the reason that forces you to reduce your driving speed? You can select more than one options.
C	Which Bridge locations do force you to minimize your driving speed?
1'	Bridges locations induce psychological fear on drivers
2'	Bridges are narrower than main traveled way
3'	Shortage of sufficient sight distance around bridge locations
a'	Bridges located on Tangent section
b'	Bridges located on horizontal curve
c'	there is no difference with location of bridge
α	Lack of Bridge width
β	Lack of sight distance on Bridge locations
μ	Problems related with either vehicle or driver
i	Clear bridge width should equal to approaching road width
ii	Clear bridge width should be wider than approaching road width
iii	There should be separated lanes for pedestrian & animal crossing
iv	Installation of appropriate notification signs
v	Installation of approaching guard rails
vi	Construction of bridges on tangent & leveled section

Appendix-E

List of Pictures taken on Study area

Photo 4: showing speed data collection tangent and horizontal curves

Photo 5: showing Speed collection on Bridges and culvert locations